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Recommendations for Control of Occupational Safety and Health Hazards . . .

Foundries

U.S. DEPARTMENT OF HEALTH AND HUMAN SERVICES
PUBLIC HEALTH SERVICE
CENTERS FOR DISEASE CONTROL
NATIONAL INSTITUTE FOR OCCUPATIONAL SAFETY AND HEALTH

HE 20.7102:

Cover photograph: This mural, representing the foundries industry, is one of fourteen murals depicting industrial scenes now on permanent display at the Greater Cincinnati International Airport. The murals, designed by Winold Reiss in the early 1930's, originally adorned the walls of Cincinnati's Union Terminal Railway Station.

RECOMMENDATIONS FOR CONTROL OF OCCUPATIONAL SAFETY AND HEALTH HAZARDS.... FOUNDRIES

U.S. DEPARTMENT OF HEALTH AND HUMAN SERVICES
Public Health Service
Centers for Disease Control
National Institute for Occupational Safety and Health
Division of Standards Development and Technology Transfer

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FOREWORD

The Occupational Safety and Health Act of 1970 (Public Law 91-596) states that the purpose of Congress expressed in the Act is "to assure so far as possible every working man and woman in the Nation safe and healthful working conditions and to preserve our human resources...by," among other things, "providing for research in the field of occupational safety and health...and by developing innovative methods, techniques, and approaches for dealing with occupational safety and health problems." Later in the Act, the National Institute for Occupational Safety and Health (NIOSH) is charged with "the development of criteria for new and improved occupational safety and health standards" to "make recommendations" concerning these standards to the Secretary of Labor. NIOSH responds to this charge by preparing Criteria Documents which contain recommendations for occupational safety and health standards.

A Criteria Document critically reviews the scientific and technical information available on the prevalence of hazards, the existence of safety and health risks, and the adequacy of control methods. The information and recommendations presented are intended to facilitate specific preventive procedures in the workplace. In the interest of wide dissemination of this information, NIOSH distributes these documents to other appropriate governmental agencies, health professionals in organized labor, industry, and academia, and to public interest groups. We welcome suggestions concerning the content, style, and distribution of these documents.

The ancient art of metal casting has long been considered to be a hazardous, dusty, noisy, and hot occupation. Many changes have occurred in foundry technology and materials, especially during the past few years; however, the basic processes and these potential hazards, have remained much the same for about 336,000 workers in U.S. foundries. This document seeks the improved protection of the health and safety of these workers.

This document was prepared by the Division of Standards Development and Technology Transfer, NIOSH. I am pleased to acknowledge the contributions made by consultants, reviewers, and the staff of the Institute. However, responsibility for the conclusions reached and the recommendations made belongs solely to the Institute. All comments by reviewers, whether or not incorporated into the final version, are being sent with this document to the Occupational Safety and Health Administration (OSHA) for consideration in standard setting.

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I. INTRODUCTION

The production of metal castings is a complex process that has long been associated with worker injuries and illnesses that are related to exposure to chemical and physical agents generated by or used in the casting process. Foundry workers may be exposed to numerous health hazards, including fumes, dusts, gases, heat, noise, vibration, and nonionizing radiation. Chronic exposure to some of these hazards may result in irreversible respiratory diseases such as silicosis, an increased risk of lung cancer, and other diseases. The foundry worker may also be exposed to safety hazards that can result in injuries including musculoskeletal strain, burns, eye damage, loss of limb, and death. The major categories of adverse health effects include: (1) malignant and nonmalignant respiratory diseases; (2) traumatic and ergonomic injuries due to falling or moving objects, lifting and carrying, etc.; (3) heat-induced illnesses and injuries; (4) vibration-induced disorders; (5) noise-induced hearing loss; and (6) eye injuries. The occurrence of these problems in a foundry should be considered as Sentinel Health Events (SHE's) [1] and may indicate a breakdown in adequate hazard controls or an intolerance to hazards in specific workers. The means for eliminating or significantly reducing each hazard are well known, widely acknowledged, and readily available. However, recent technological changes introduce new chemical and physical agents, as well as new process machinery, which could create further risks to worker safety and health.

Published scientific data on occupational injuries and illnesses in foundry workers, working conditions, and the engineering controls and work practices used in sand-casting foundries are reviewed in this document. Based on an evaluation of the literature, recommendations have been developed for reducing the safety and health risks related to working in sand-casting foundries. Because of the diversity and complexity of the foundry industry, this document is limited to those facilities that pour molten metal into sand molds. Although die, permanent mold, investment, and other types of casting are not specifically addressed, many of the processes and materials are similar to those used in sand casting; the recommendations in this document may apply to those foundries as well. However, only those processes, materials, and work procedures specific to sand casting are discussed. The specific operations in die and permanent mold casting are excluded from the scope of the document because process equipment and work procedures differ from those in sand casting, and the hazards to safety in die and permanent mold casting could not be adequately covered here. In addition, most die and permanent mold castings (with the exception of gravity cast permanent mold casting) are not constructed with sand cores and do not require the extensive cleaning operations necessary for sand castings.

The foundry operations that have been studied include: (1) handling raw materials such as scrap metal and sand; (2) preparing sand; (3) making molds and cores; (4) reclaiming sand and other materials used in mold and core production; (5) melting and alloying metals; (6) pouring; (7) removing cores and shaking out castings; (8) rough cleaning of castings including chipping, grinding, and cut-off operations; (9) maintaining and repairing equipment used in coremaking, moldmaking, and in melting, pouring, shakeout, and rough cleaning operations; and, (10) cleaning foundry areas in which molding, coremaking, melting, pouring, and rough cleaning of castings occur. Patternmaking operations have not been included because not all foundries have patternmaking shops, and hazards in patternmaking are related more to wood, metal, and plastic fabrication operations. Also, final cleaning and other ancillary processes, such as welding, arc-air gouging, heat treating, annealing, x-ray inspection of castings, machining, and buffing, are not discussed in this document.

II. INDUSTRY AND PROCESS DESCRIPTION

Founding or casting, is the metal-forming process by which molten metal is poured into a prepared mold to produce a metal object called a casting. These metal-casting operations are carried out in facilities known as foundries [2]. All founding involves the melting of metal, but production of metal castings varies greatly depending on many factors such as the mold material; type of metal cast; production rate; casting size; and age, size, and layout of the foundry. The primary way to cast metals is by using sand and a bonding agent as mold materials [3]. Sand casting is best suited for iron and steel because of their high melting temperatures, but it is also used for nonferrous metals such as aluminum, brass, bronze, and magnesium [3,4,5,6,7].

The production of castings where sand is used as a mold material requires certain basic processes. These include (1) preparing a mold and core into and around which the molten metal may be poured, (2) melting and pouring the molten metal, and (3) cleaning the cooled metal casting with eventual removal of molding material and extraneous metal [2,3,4,5,6,8]. A schematic diagram of the overall foundry process is presented in Figure II-1. Some of the terms common to foundry processes are defined in the Glossary for Foundry Practice [9] and in Chapter X (Appendix A - Glossary of Terms).

A. Industry Description

In 1983, the metal-casting industry produced approximately 27.8 million tons of metal casting and employed approximately 336,200 workers [10], and encompassed a major segment of our national economy. Based on total sales, the cast metals industry is the sixth largest industry in the United States. Total tonnage and dollar value of casting production, which had increased in the 1970's, has declined during the past several years. In 1979, a total of 18.9 million tons of metal castings were produced vs. 15.3 million tons produced in 1981 and 10.5 million tons in 1982. In recent years, the foundry industry has had a trend toward fewer, but larger, foundries [10].

The majority of castings are component parts used in a wide range of industries with 90% of all durable goods using castings to some degree [10]. Cast parts range in size from a fraction of an inch and weighing a fraction of an ounce, such as individual teeth on a zipper, to those measuring 30 feet (9 meters) or more and weighing many tons, such as the huge propellers and stern frames on ocean liners, frames for pumps and milling machines, etc. [10,11].

The Standard Industrial Classifications (SIC) used by the U.S. Department of Commerce categorizes plants according to their major end products. Foundries that make cast metal items for independent sale, the jobbing foundries, are listed in several SIC groups under two major categories: (1) ferrous foundries, which include gray ductile iron, malleable iron, and

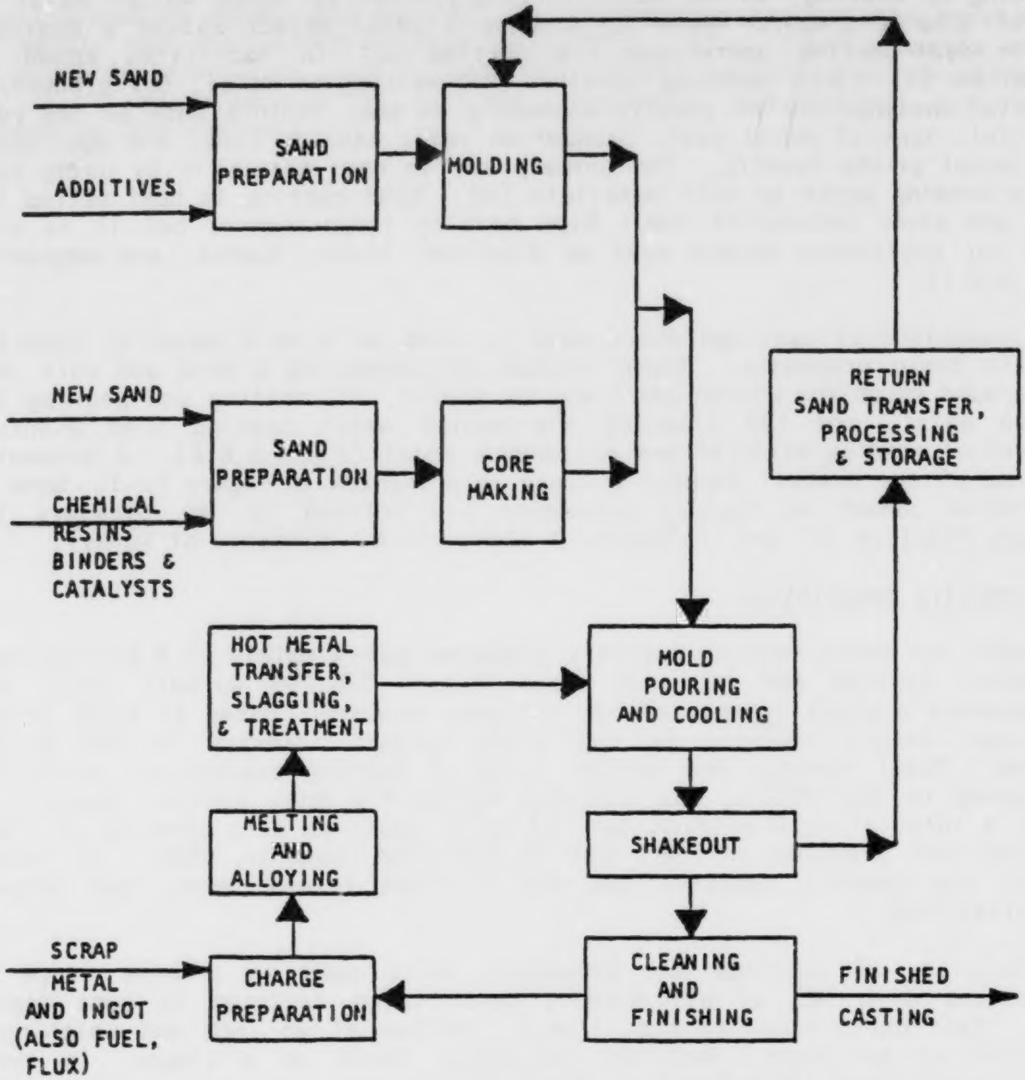
NEW SAND
ADDITIVES
SAND PREPARATION
MOLDING
NEW SAND
CHEMICAL RESINS BINDERS & CATALYSTS
SAND PREPARATION
CORE MAKING
RETURN SAND TRANSFER, PROCESSING & STORAGE
HOT METAL TRANSFER, SLAGGING, & TREATMENT
MOLD POURING AND COOLING
MELTING AND ALLOYING
SHAKEOUT
SCRAP METAL AND INGOT (ALSO FUEL, FLUX)
CHARGE PREPARATION
CLEANING AND FINISHING
FINISHED CASTING

FIGURE II-1. Schematic diagram of overall foundry process

Adapted from reference [7]

steel foundries; and (2) nonferrous foundries, which include aluminum, brass, bronze, copper-based alloys, zinc, magnesium, etc. [10].

In addition to the 3,180 jobbing foundries in 1983, there were 824 captive foundries that produced metal castings for use within a larger manufacturing process. Because the captive metal-casting operations are incorporated within many different industrial classifications, such as Motor Vehicles, Agricultural Equipment, and Plumbing Fixtures Manufacture, the number of captive foundries in the United States is not readily apparent within the foundry SIC's [10].

The 1984 Metal Casting Industry Census Guide [10] estimated a total of 4,004 foundries employing 336,200 workers in the United States, of which the captive foundries produced approximately 45% of the total tonnage. Data on the types of furnaces used are presented in Table II-1. Table II-2 presents data on the size of these foundries and the types of metal cast. Some foundries cast more than one type of metal, and, therefore, the number of foundries listed by type of metal cast is larger than the actual 4,004 separately identified foundries. Table II-3 lists occupations grouped by job category in foundries where different exposures to hazardous physical or chemical agents may occur or where safety hazards may exist. In some small foundries, workers will have more than one job function and may be exposed to hazards in two or more of the occupations listed.

TABLE II-1. Melting furnace usage, 1984

Type of furnace	Number
Cupolas	537
Open hearth	17
Air	13
Electric arc	355
Channel induction	536
Coreless induction	1,087
Crucible	2,039
Reverberatory	538
Noncrucible	193
Total	5,315

Adapted from reference [10]

TABLE II-2. Analysis of foundries in the United States, 1984

Characteristics	Number of foundries
Size of foundries (Number of workers)	
≥1,000	26
500 - 999	56
250 - 499	174
100 - 249	518
50 - 99	597
20 - 49	952
<20	1,681
Total	4,004
Casting methods	
Carbon dioxide mold	499
Centrifugal	240
Die-casting	620
Investment mold	355
Permanent mold	608
Plaster mold	179
Green sand	2,765
Shell mold	445
Total	5,711
Type of metal cast	
Aluminum	2,197
Brass and bronze	1,447
Ductile iron	564
Exclusive nonferrous	2,346
Gray iron	1,156
Magnesium	103
Malleable	87
Nonferrous departments	534
Steel	684
Zinc	729
Total	9,847

Adapted from reference [10]

TABLE II-3. Occupations with potential exposure to safety and health hazards in foundries

Department	Job category
Cleaning and finishing	Burners Casting repair welders Chippers Grinders Sandblasters Shakeout men Tumbler operators
Coremaking	Bench coremakers Core assemblers Core-oven tenders Core-sand mixers Sand technicians Miscellaneous
Melting and pouring	Brick masons Crucible melters Cupola tenders Electric furnace tenders Furnace changers Laborers including ladlemen Ladle pourers
Miscellaneous	Carpenters Crane operators Electricians Floor sweepers Forklift operators Mechanical pipe fitters Mechanics Millwrights Truck drivers
Molding	Bench molders Floor molders Machine molders Molders' helpers Mulling machine operators

Adapted from reference [3]

B. Process Description

A pattern is a form made of wood, metal, or other suitable material, such as polystyrene or epoxy resin, around which molding material is packed to shape the mold cavity [3,5,8,9]. The pattern is the same shape as the final casting, except for certain features which are designed to compensate for contraction of the liquid metal when cooling and an allowance to facilitate removing the pattern from the sand or other molding medium [3]. The pattern determines the mold's internal contour mold and the external contour of the finished casting. Although patterns are required to make molds, many foundries do not make their own patterns. The hazards in patternmaking are primarily those present in woodworking industries, and, consequently, the recommended controls are similar to those for woodworking.

1. Molding

The mold provides a cavity into which molten metal is poured to produce a casting. Sand combined with a suitable binder is packed rigidly around a pattern so that a cavity of corresponding shape remains when the pattern is removed. The physical and chemical properties of sand account for its wide use in producing castings. Sand can be formed into definite shapes, it prevents fusion caused by the high temperature of the metal, and it contains enough permeability to permit gases to escape. The sand mold is friable, and after the metal is cast, it can be readily broken away for removal of the casting [3,4,5].

Types of sand molding include green, dry, no-bake, shell, hot- and cold-box, skin-dried, and dry sand-core molds. Green-sand molding, the most widely used molding process, is composed of sand, clay, water, and other materials [3,5,12]. In green-sand molding, the mold is closed, and the metal is poured before appreciable drying occurs. Depending on the type of clay used, these molds may contain 3-5% moisture [3,5,12,13]. Both ferrous and nonferrous castings are produced in green-sand molds.

A recently developed approach to dry-sand molding is the "V PROCESS" which uses unbonded sand with a vacuum. The dry-molding sand is rigidized by vacuum packing it in a plastic film during mold production. The plastic film is vacuum formed against the pattern; the flask is positioned and filled with dry unbonded sand and then covered with a plastic film and made rigid by drawing a vacuum through the sand [14].

Dry-sand molds are oven dried to a depth of 0.5 inch (1 centimeter) or more. Molds are baked at 150-370°C (300-700°F) for 4-48 hours depending upon the binders used, the mass of the mold, the amount of sand surface to be dried, and the production cycle requirements [3,5]. Dry-sand molds are generally used for larger castings, such as large housings, gears, and machinery components. Large molds and pit molds are usually skin dried to remove surface moisture to a depth of 0.5 inch by air or torch drying.

No-bake systems are used for molding; these systems cure at room temperature. No-bake sand systems include the furan, alkyd oil, oil-oxygen, sodium silicate ester, phenolic, phosphate, urethane, and cement molding processes [3,5,15,16]. All of these are composed of sand with binder materials and are made by the sand-molding methods; these molds have a very low water content, usually less than 1% except sodium silicate-carbon dioxide (CO_2) and cement molds.

Molds can also be made by using the shell, hot-box, and cold-box processes. The shell and hot-box processes need heat to cure the binder system; the cold-box process uses a gas to cure the binder system. See Section II.B.2. Coremaking, for a more detailed description of these procedures.

Silica sand is used for most sand-molding operations; however, olivine, zircon, and chromite sands have also been used as substitutes for silica sand in ferrous, as well as nonferrous, foundries [17,18]. Naturally bonded sand is cohesive because it contains clay or bonding material as mined; synthetically bonded sand is formed by mixing sand with a binding agent, e.g., western or southern bentonite clays, kaolin, or fireclay [9,12,16]. The term synthetic is somewhat of a misnomer because it is not the sand that is synthesized but the sand-clay mixture [12].

Synthetically bonded sands are used in foundries producing castings from high melting point metals such as steel because the composition of these sands is more readily controlled. Various mixtures of naturally bonded and synthetically bonded sands have had limited use for malleable and gray iron. Naturally bonded sands are generally satisfactory for the lower melting point metals [3,5].

Although the basic molding ingredients are sand and clay, other materials are often added in small amounts for special purposes. For example, carbonaceous materials such as seacoal, pitch, and lignite are added to provide a combustible thermal expansion cushion, as well as a reducing atmosphere, and to improve the casting surface finish. Cereals, gelatinized starches, and dextrin provide a reducing atmosphere, increase dry strength, and reduce the friability of air-dried molds [16].

Sand molds, especially for large castings, frequently require special facing sands that will be in contact with the molten metal. Facing sands are specially formulated to minimize thermal expansion and are usually applied manually by the molder. Mold coatings or washes, are used to obtain better casting finishes. The coating is applied by spraying, brushing, or swabbing to increase the refractory characteristics of the surface by sealing the mold at the sand-metal interface. Mold coatings resemble paints and generally contain a refractory filler, a vehicle, a suspension agent, and a binder. The mold coating filler material for steel castings is usually zircon or chromite flour; the vehicle is water or commercial grade alcohol. The suspension agent is bentonite or sodium algenate. When an alcohol vehicle is used, the molds are usually torch dried to burn off the alcohol [3].

Sand may be prepared and conditioned for molding by mixing ingredients in a variety of mechanical mullers and mixers. Conditioning of molding sands may include mixing sand with other ingredients such as clay and water, mulling the ingredients, cooling the sand from shakeout, and removing foreign material from the sand [3,5]. Usually, mixers are not used for clay-bonded sands. Sand is reclaimed by one of three methods: (1) using air separators to remove fines, such as silica flour and clay (dry reclamation), (2) slurrying sand with water (wet reclamation), or (3) heating sand to remove carbonaceous and clay materials (thermal reclamation) [3].

Prepared sand is discharged from the mixer or muller and is transferred to the molding area. Types of molding include: bench molding (molds manually prepared on a bench), floor molding (performed on the foundry floor), pit molding (molds are made within depressed areas of the floor), and machine molding [4].

In some cases, the patterns are dusted with a parting powder or washed with a parting liquid to ease the release of metal from the mold after pouring. Before World War II, the parting powders were almost entirely composed of silica dust [19], but due to the silicosis hazard, nonsilica materials such as nonsiliceous talc have sometimes been substituted. The use of liquid parting washes has also reduced the hazard of silica dust exposure.

2. Coremaking

A core defines the internal hollows or cavities desired in the final casting. Cores are composed mainly of sand but may contain one or more binder materials, including organic binders such as oils and resins and inorganic binders such as cements and sodium silicate. A gas or liquid catalyst may be used, depending upon the formulation. Many factors, including moisture content, porosity, core complexity, quantity of cores required, and raw material used, need to be considered when selecting the core formulation and process best suited for a particular application.

Most of the techniques used to make a sand mold also apply to making a sand core. Cores are made by mulling or mixing the required ingredients and then manually or mechanically putting these materials into a corebox. The principal corebinding systems are listed in Table II-4 [20].

Phenol-formaldehyde resins are currently used in the oven-baking, shell, hot- and cold-box, and no-bake processes. Most of the shell cores and molds are produced by these resins [21]. The cores and molds are produced by dumping a resin-coated sand onto a heated pattern, holding the core materials for a sufficient time to achieve curing at the pattern surface, dumping excess sand out of the core, and then stripping the hollow-cured shell from the pattern [13]. Hexamethylenetetramine (Hexa) in amounts of 10-17% (based on resin weight) is used as a catalyst

TABLE II-4. Types of core binders

	Thermosetting	Self-setting
Organic	Shell: dry blend, warm coat (solvent), and hot coat	No-bake: alkyd oil furans phenolics urethanes
	Hot box: furan and phenolic	Cold box (gassing): silicate CO_2 urethane amine furan SO_2
	Oven: core oils phenolics	No-bake: silicate ester phosphate cements/silicates/slags fluid sands
Inorganic	Silicates: (warm box)	

Adapted from reference [20]

for the curing reaction [21]. Lubricants such as calcium stearate or zinc stearate are added to the resin-sand mixtures for easy release of the core from the pattern and to improve the fluidity of the sand [3].

Hot-box cores are typically solid, rather than shells, and contain resins that polymerize rapidly in the presence of acids and heat. Resins used for hot-box cores include modified furan resins, composed of urea-formaldehyde and furfuryl alcohol, or urea-phenol-formaldehyde, commonly called phenolic resins. Furan and phenolic resin in the presence of a mold catalyst will polymerize to form a solid bonding agent. Urea is not a constituent of these resins in steel foundries because it can cause casting defects [3]. More recently, urea-free phenol-formaldehyde-furfuryl alcohol resinous binders have been developed for use in producing hot-box cores [13].

Cold-box systems require the use of a gaseous catalyst rather than heat to cure the binder systems and to produce a core or a mold. There are three cold-box "gassing" systems: one uses carbon dioxide (CO_2) and a sodium silicate binder; another uses amine gases (TEA - triethylamine; DMEA - dimethylethylamine) and a two part binder system composed of a diphenylmethane diisocyanate (MDI); the third gassing system uses sulfur dioxide (SO_2) gas and a two part binder system made up of a furan binder and a peroxide, usually methyl ethyl ketone peroxide (MEKP). In the presence of the catalyst gas, each binder system forms a (solid) resin film which serves as the sand binder. Following introduction of the amine or SO_2 catalyst, air is used to sweep the remaining gas vapors from the core (or mold), after which the sand core (or mold) is removed from the pattern. Not all the vapors are completely purged, and some offgassing may continue. Chemical scrubbers are used to remove the amines and SO_2 gases from the air purge cycle and from the work areas. The CO_2 gassing cold-box system requires no air scrubbing.

No-bake binders represent modifications of the oleoresinous, furan, sodium silicate, phenol-formaldehyde, and polyurethane binder systems. Various chemicals are incorporated in an unheated corebox to cause polymerization [13].

3. Melting

Cupolas and electric, crucible, and reverberatory furnaces are used to melt metals. For melting iron, especially gray iron, the cupola furnace is most often used [5,10,22,23]. Many fundamental cupola designs have evolved through the years including the conventional refractory-lined cupola and the unlined water-cooled cupola [23,24].

In all cupola designs (Figure II-2), the shell is made of steel plates. In the conventional design, an inside lining of refractory material insulates the shell. In unlined, water-cooled cupolas, cooling water flowing from below the charging door to the tuyeres, or air ports, is used on the outside of the unlined shell. An inside lining of carbon block is used below the tuyeres to the sand bed, to protect the shell from the high interior temperature [5,22,23,24].

The cupola bottom may consist of two semicircular, hinged steel doors that are supported in the closed position by props during operation but can be opened at the end of a melting cycle to dump the remaining charge materials. To prepare for melting, a sand bed 10-60 inches (0.2-1.5 meters) deep is rammed in place on the closed doors to seal the cupola bottom. At the beginning of the melting cycle, coke is placed on top of the sand and ignited, usually with a gas torch or electric starter. Additional coke is added to a height of 4-5 feet (1.2-1.5 meters) above the tuyeres, after which layered charges of metal, limestone, and coke are stacked up to the normal operating height [24].

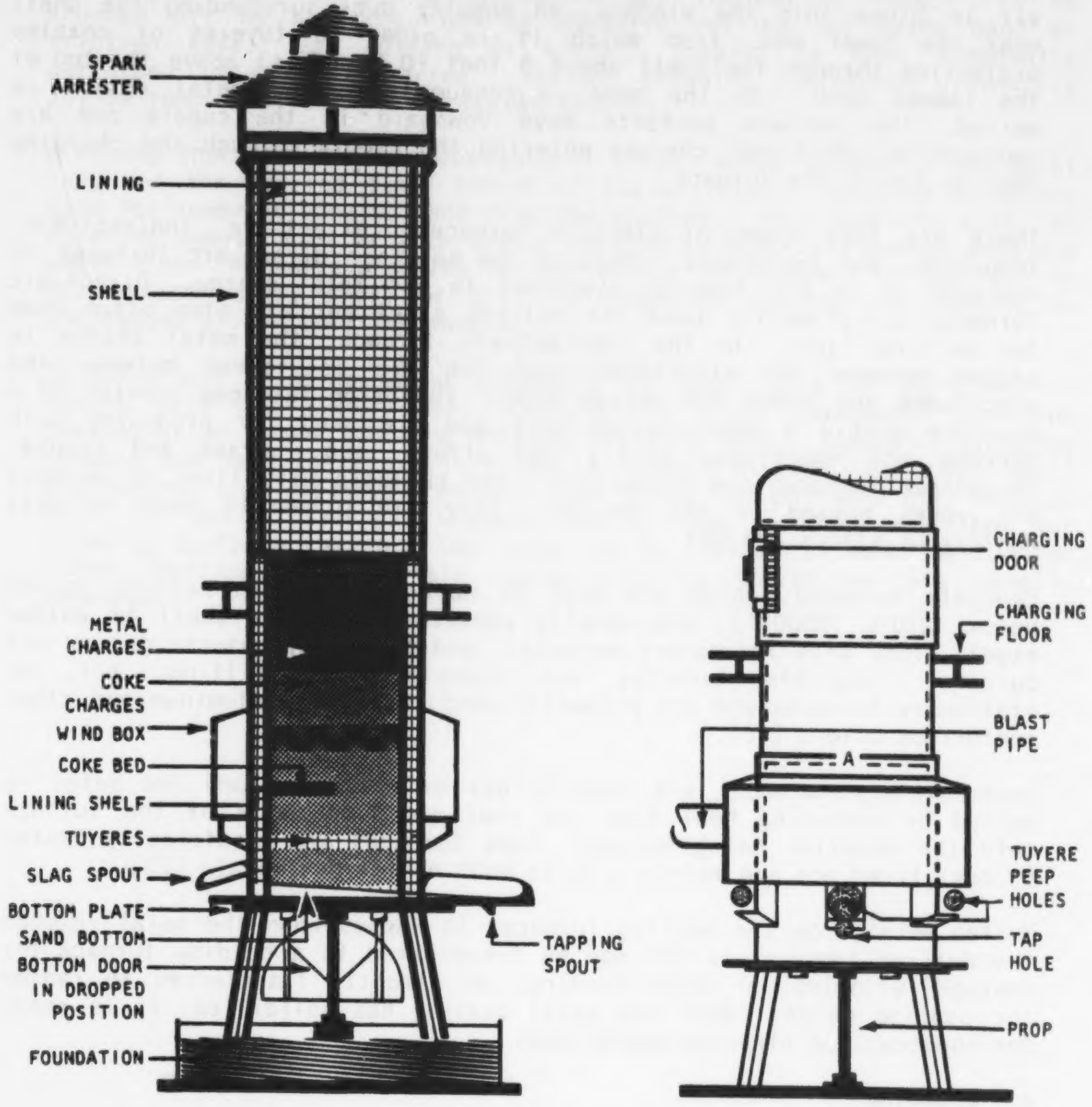
SPARK ARRESTER
LINING
SHELL
METAL CHARGES
COKE CHARGES
WIND BOX
COKE BED
LINING SHELF
TUYERES
SLAG SPOUT
BOTTOM PLATE
SAND BOTTOM
BOTTOM DOOR IN DROPPED POSITION
FOUNDATION
TAPPING SPOUT
CHARGING DOOR
CHARGING FLOOR
BLAST PIPE
A
TUYERE PEEP HOLES
TAP HOLE
PROP

FIGURE II-2. Cupola furnace

Adapted from reference [23]

The airblast is turned on and the melting process begins. Combustion air is blown into the windbox, an angular duct surrounding the shell near the lower end, from which it is piped to tuyeres or nozzles projecting through the shell about 3 feet (0.9 meters) above the top of the rammed sand. As the coke is consumed and the metal charge is melted, the furnace contents move downward in the cupola and are replaced by additional charges entering the cupola through the charging door on top of the furnace.

There are four types of electric furnaces: direct-arc, indirect-arc, induction, and resistance. Melting the metal in direct-arc furnaces is achieved by an arc from an electrode to the metal charge. Direct-arc furnaces are primarily used for melting steel but are also often used for melting iron. In the indirect-arc furnace, the metal charge is placed between the electrodes, and the arc is formed between the electrodes and above the charge [23]. Induction furnaces consist of a crucible within a water-cooled coil and are used for producing both ferrous and nonferrous metals and alloys, e.g., brass and bronze. Resistance furnaces are refractory-lined chambers with fixed or movable electrodes buried in the charge. They are primarily used to melt nonferrous alloys [23,25].

Crucible furnaces, which are used to melt metals with melting points below 1370°C (2500°F), are usually constructed with a shell of welded steel, lined with refractory material, and heated by natural gas or oil burners. Crucible furnaces are classified as tilting, pit, or stationary furnaces and are primarily used in melting aluminum and other nonferrous alloys [23].

Reverberatory furnaces are usually gas or oil fired and the metal is melted by radiating heat from the roof and side walls of the furnace onto the material being heated. Some furnaces are electrically heated or coal fired and are mainly used to melt nonferrous metals [23].

Molten metal from the melting furnaces is tapped when the metal reaches the desired temperature and may be transferred to a holding furnace for storage, alloying, or super heating, or directly transferred to ladles for pouring molds. When the metal casting has solidified, it is ready for shakeout and cleaning operations.

4. Cleaning

Cleaning operations involve removing sand, scale, and excess metal from the casting [3,5]. The cleaning process includes shakeout; the removal of sprues, gates, and risers; abrasive blasting; and, grinding and chipping operations.

Removing the sprues, gates, and risers is usually the first operation in cleaning. The gating system may be cut or broken off when the castings are dumped out of the flask onto a shakeout screen or table. Sprues, gates, and risers may also be removed by striking them with a hammer. The vibratory action of the shakeout causes the sand to fall from the casting into a hopper below. The cast article is then moved for further cleaning. When the gating system is not removed by impact, it is knocked off by shearing, gas or abrasive cutting, or using band or friction saws. Gas cutting or arc-air gouging is most frequently performed in steel foundries. Surface cleaning operations ordinarily follow removal of the gating system [3,5,7].

Cleaning the castings involves several steps, which vary with the metal used and the desired final finish of the articles. Tumbling mills are used for removing adhered sand from the casting. In a tumbling mill, an abrading agent, such as jack stars, is used to knock off excess sand and small fins. Abrasive blasting is carried out in chambers or cabinets in which sand, steel shot, or grit is propelled against the casting by compressed air or rotating wheels.

Chipping and grinding using pneumatic or hand tools is performed to remove gate and riser pads, chaplets, or other appendages from the casting or to remove adhering molding and core sand. Pneumatic chipping hammers are used to remove fins, scale, burned-in sand, and other small protrusions from castings. Bench, floor stand, or portable grinders are used for small castings; whereas, swing-frame grinders are used for trimming castings that are too heavy to be carried or hand held. For higher melting alloy metals, more cleaning operations are usually required.

III. HEALTH AND SAFETY HAZARDS

A. Introduction

Foundry workers may be exposed to many potential health and safety hazards [4,8]. These potential hazards along with their health effects and exposure limits are summarized in Appendix B. Sand-handling, sand preparation, shakeout, and other operations create dusty conditions exposing the worker to free silica. Chipping and grinding operations to remove molding sand which adheres to the casting may create a dust hazard in the foundry cleaning room area [7]. Mechanical sand removal aids, such as abrasive blasting machines, that operate on the principles of impact or percussion create high noise levels [13,26]. Foundry workers may be affected by the heat produced during melting and pouring operations [26]. In addition, the handling of molten metal and manual handling of heavy materials contribute to the burns and musculoskeletal illnesses and injuries suffered by foundry workers.

Respiratory disorders, particularly silicosis, are among the most commonly reported occupational health effects in foundry workers. As early as 1923, Macklin and Middleton [27] found that 22.8% of the 201 steel-casting dressers examined had pulmonary fibrosis. In 1936, Merewether [28] reported that after 10 years of employment, seven sandblasters of metal castings had died from silicosis at an average age of 40.7 years. After 8 years of employment, 16 sandblasters had died from silicosis complicated by tuberculosis. The average age at the time of death was 44.2 years. Unless sandblasting of castings was conducted in an enclosed chamber that allowed the operator to remain outside, the worker could not work at the trade for more than 1-2 years without serious lung disease. In the United States, Trasko [29] (using state records) identified 12,763 reported cases of silicosis during 1950-56. Of all the industries having a silicosis hazard, 16% of the total identified cases occurred in the foundries as compared to 66% in the mining industries and 18% in the pottery, brick, stone, talc, clay, and glass industries combined. Although foundry operations and conditions have changed considerably for the better since these early historical studies, there are a number of more recent studies [30,31,32,33,34] which indicate that silicosis still occurs. Recent comprehensive epidemiologic studies on the prevalence of fibrotic lung disease in foundry workers are lacking; however, data from NIOSH Health Hazard Evaluations (HHE's) [35,36,37,38] and recent Occupational Safety and Health Administration (OSHA) consultation visits [39] show that silica levels exceeding the NIOSH recommended exposure limit (REL) and the OSHA permissible exposure limit (PEL) do occur in both ferrous and nonferrous foundries, creating a potential increased risk of silicosis for foundry workers.

An increased risk of lung cancer among foundry workers has been shown in a number of studies [30,31,40,41,42,43,44,45]. Based on 1931 census data, the relationship between occupation and cancer deaths in the Sheffield, England foundries was studied in a population of approximately 178,600 male workers over 14 years of age and retired workers. Of all occupations, the furnace and foundry workers had the highest mortality rate from lung cancer; the lung cancer deaths were 133% above the expected rate (126 observed vs. 54 expected) [45].

The potential for lung cancer is not merely of historical interest. In the recent reports of Egan et al. [31,41], an increased risk of death from cancer of the trachea, bronchus, and lung was reported among foundry workers with a proportional mortality ratio (PMR) of 176 for black and of 144 for white workers, ($p<0.01$ for both). Statistically significant increases in deaths for respiratory tuberculosis with a PMR of 232 for white workers ($p<0.05$) and in deaths for nonmalignant respiratory disease with a PMR of 138 for white workers ($p<0.01$) and of 151 for black workers ($p<0.05$), were also reported. These findings were based on an analysis of the death certificates of 2,990 foundry workers who had died between 1971-75 and who had paid monthly union dues from at least 1961 until the time of death or until receiving a 45-year life membership card. Histories of smoking and occupational exposure to carcinogenic agents, which are important causative factors in lung cancer, were lacking. Processes and materials which have been introduced into foundry technology over the past 20-30 years complicate the problem of identifying potential etiologic carcinogenic agents [31,41,46].

In a recent comparison of the relative risk of death from lung cancer among a cohort of 1,103 nonfoundry and 439 foundry workers, the overall death rate and incidence of neoplasms were not significantly increased, but risk of death from lung cancer was five times higher in the foundry workers with a standardized mortality ratio (SMR) of 250 and $p<0.01$ [30]. A 1981 review of the lung cancer data in foundry workers showed that particularly the molders, metal pourers, and cleaners have a two- to threefold increased risk of death from lung cancer [47].

The working conditions in foundries are further complicated by the safety hazards which may be confronted on a daily basis by foundry workers. These conditions have resulted in minor, as well as major, traumatic injuries and deaths. The incidence rate of lost workday cases of disabling injuries and illnesses in California foundries in 1975 per 100 workers was almost three times that in manufacturing as a whole [48]. National Safety Council (NSC) [49] data also indicate that foundries have higher injury and illness rates than other industries (Table III-1). In 1980, similar high accident rates were reported for the Ohio foundries in 1980 [50]. Statistical studies of foundry injuries show that foundry workers have a wide range of on-the-job injuries such as loss of limbs, burns, strain and overexertion, and foreign particles in the eyes [48,50,51,52]. Based on these data, foundries were designated by OSHA as a high hazard industry and selected as a first project under the National Emphasis Program (NEP) [53].

Studies of health effects presented later in this chapter show that in addition to being at risk for developing certain chronic respiratory diseases such as silicosis and lung cancer, foundry workers may be exposed to health hazards which could result in carbon monoxide poisoning, metal fume fever, respiratory tract irritation, dermatitis, and other illnesses.

TABLE III-1. Recordable occupational injury and illness incidence rates by industry, reported to the National Safety Council, 1981-83*

Industry	SIC[a] code	Total recordable cases	Total lost workday cases	Cases involving days away from work and death	Nonfatal cases without lost workdays	Total lost workdays
		Incidence rates per 100 full-time workers				
Iron and steel foundries	332	12.51	5.11	2.86	7.40	83
Nonferrous foundries	336	9.41	4.09	2.65	5.32	74
Construction	15-17	10.51	4.01	3.54	6.48	71
Mining	10-14	6.13	1.99	1.73	4.13	58
Manufacturing	20-39	6.82	2.70	1.93	4.11	51
All Industries	--	6.75	2.98	2.22	3.77	54

[a] 2- and 3-digit Standard Industry Classification (SIC)

*Adapted from reference [49]

B. Health Hazards in Foundries

The potential health hazards present in the working environment of foundries are dependent upon a number of factors. Among these are the types of processes employed and the materials used in each process, including the type of metal cast, size of castings produced, sand-to-metal ratio, molding material bonding agents used, engineering controls, ventilation, building design, etc.

Health hazards in foundries include: (1) chemical hazards such as silica and other nonmetallic dust, metal dusts and fumes, carbon monoxide, and other chemical compounds including thermal decomposition products; and, (2) physical hazards associated with various foundry processes such as noise, vibration, and heat.

1. Chemical Hazards

a. Silica and Other Nonmetallic Substances

Crystalline silica dusts present the greatest and most widespread hazard to the health of foundry workers. Silica is silicon dioxide (SiO_2) that occurs both in a crystalline form, in which molecules are arranged in a fixed pattern, and in an amorphous form where molecules are randomly arranged. The fine silica dust in foundries and other industries is produced by rubbing, abrading, or mechanical action on quartz sand, which is composed primarily of crystalline silica. Quartz sand is the main molding material in iron and nonferrous foundries and in many steel foundries. Silica refractories are used to line many foundry furnaces and ladles. When quartz is heated, the crystalline structure slowly changes to produce tridymite (above 860°C) and cristobalite (above 1470°C), which are considered even more fibrogenic to the lungs than quartz [54]. In 1983, OSHA established PEL's for cristobalite and tridymite which are one-half that for quartz [55].

The major foundry operations that produce fine particle-size silica dusts are sand-mold preparation, removing the castings from the mold, and cleaning the castings. A large quantity of dust arises from cleaning with pneumatic chisels and portable grinders and during abrasive blasting and tumbling. Molding and coremaking operations are less dusty, especially when damp or chemically-bonded sand is used. Preparing and reclaiming sand and repair and maintenance of process equipment are also potentially hazardous in terms of crystalline silica dust producing diseases [7,19]. An increased hazard has been created in the past by the coating of molds, patterns, and cores with finely divided high silica-containing dry powders and washes [56]. The extent to which crystalline silica exposure creates a significant hazard in a given foundry depends upon the size and type of the foundry, the arrangement of processing within it, the adequacy of dust controls, and the standards for housekeeping and other work practices [57].

The fibrotic reaction of the lung tissue to the accumulation of respirable crystalline silica is a pneumoconiosis known as silicosis [58,59,60,61,62]. The onset of this disease is slowly progressive. Usually after several years of exposure to silica dust of respirable size (<10 micrometers in diameter), the worker may develop fibrotic changes in the lungs and may become progressively more breathless, often developing a persistent cough. As the fibrosis progresses, it produces abnormalities which on the x-ray film appear as nodules that ultimately may coalesce. The silicotic lung is more susceptible to infections, particularly to tuberculosis, and may lead to cardiopulmonary impairment and cardiac failure [59]. Other dust-related lung disorders, such as benign siderosis, may be confused on the x ray with the diagnosis of silicosis [63].

Other refractory materials are also used in foundry operations. In some cases, usually in steel foundries, asbestos has had a limited application in riser sleeves and in the lining of furnaces and ladles [31]. Talc (of unspecified composition) is a silicate sometimes used as a parting agent in many foundries. Talc appears to be less fibrogenic than crystalline silica and is generally regarded as a safer substitute for the fibrogenic silica flour [19] unless the talc is contaminated with asbestiform fibers. Other refractories, such as silicates, alumina, mullite, sillimanite, magnesia, and spinel, are considered unlikely to constitute a serious hazard to foundry workers [19], but little research has been done on these compounds.

Other sands are used with silica sand for special casting purposes. For example, steel foundries use zircon or chromite sands to prevent metal penetration at the mold-metal interface. Zircon and olivine sands have not been studied to determine their fibrogenic effects in humans.

b. Metal Dusts and Fumes

Metal dusts may be released into the foundry environment during the charging of the furnaces and the cleaning of castings. Metal fumes are emitted during melting and pouring processes, sometimes in large quantities, when one component metal has a lower boiling temperature than the melt temperature.

Lead (Pb) is a hazard in those foundries where it is used in the melt or is present in contaminated scrap, but the hazards from Pb or Pb contaminated dust and fume exist principally in nonferrous foundries producing leaded bronzes. Early symptoms of Pb poisoning are nonspecific and may include fatigue, pallor, disturbance of sleep, and digestive problems. Individuals may also develop anemia and severe abdominal pain from Pb colic. Central nervous system (CNS) damage, peripheral neuropathy, or kidney damage may occur [58,59,64].

Inhalation of freshly formed oxides of some metals may give rise to metal fume fever, otherwise known as brassfounders' ague, Monday fever, or foundry fever. Although metal fume fever is most commonly associated with the inhalation of zinc oxide fumes, other metals or their oxides, including copper and magnesium [58,65,66], may cause this condition. The syndrome usually begins with a metallic-like taste in the mouth followed by a dry throat, fever, and chills accompanied by sweating, generalized aches and pains, and fatigue, all of which usually disappear within 24-48 hours. This tolerance to metal fumes tends to be lost quickly, and the symptoms commonly reappear when the individual returns to work after a weekend or after a holiday [19,58].

Some metals to which the foundry worker may be exposed are either known or suspected carcinogens. Certain forms of chromium VI [61,67] (used as a trace alloying element) have been found to increase respiratory cancer mortality among workers; nickel and beryllium (used as a nonferrous alloy) are potential human carcinogens [61,68] (see Appendix B).

c. Carbon Monoxide

Carbon monoxide (CO), produced by the decomposition of sand binder systems and carbonaceous substances when contacted by the molten metal, is a common and potentially serious health hazard in foundries. It may be produced in significant quantities during preheating of the furnace charge, melting or pouring, ladle or core curing, or from any other source of combustion, including space heating equipment or internal combustion engines; it may also evolve from indoor settling ponds for cupola or scrubbers [69,70,71].

Carbon monoxide quickly combines with blood hemoglobin to form carboxyhemoglobin which interferes with the oxygen carrying capacity of the blood, resulting in tissue anoxia. Symptoms of CO poisoning may include headache, dizziness, drowsiness, nausea, and vomiting [70,71].

d. Other Chemical Hazards

Other chemicals which are present in the foundry environment can have adverse health effects. Numerous chemical compounds or their decomposition products may result from binding agents, resins, and catalysts used in sand molds and cores. Additional emissions may be generated by paints, oils, greases, and other contaminants present in scrap metal and other materials introduced into the melting furnace [13,15,69,72,73]. Data on the potential health hazards of some chemicals, chemical binding systems and their emissions, and foundry processes are listed in Table III-2 for a simulated mold pouring. These data do not represent actual breathing zone samples collected from workers. Data are listed in Tables III-3 and III-4 and Appendix B for coremaking [72,74].

(1) Amines

Triethylamine (TEA) and dimethylethylamine (DMEA) are used as catalysts in a cold-box system. These amine catalysts are volatile and flammable, and vapors may present a safety hazard. TEA exposure in industry can result in eye and lung irritation as well as halo vision at high TEA concentrations [15,69].

(2) Ammonia

Ammonia (NH_3) is produced during core curing of nitrogen-containing organic binders and during thermal decomposition of hexamethylenetetramine catalyst. It is also formed when pouring molten metal into cores of nitrogen-containing organic binders [13,15,69,75,76]. Ammonia is extremely irritating to the eyes and respiratory tract and in high concentrations may result in chronic lung disease and eye damage [58,61,69,77]. Continued worker exposure to a high concentration is intolerable.

(3) Benzene, Toluene, and Xylene

Decomposition of organic materials used during metal-pouring operations may produce a wide variety of aromatic compounds including benzene [72]. Chronic benzene exposures may cause

TABLE III-2. Hazard evaluation of potential chemical emissions during simulated foundry molding

Chemicals	Green sand	Dry sand	Sodium silicate ester	Core oil	Alkyd isocyanate	Phenolic urethane	Phenolic no-bake	Low N2 furan H3PO4	Med N2 furan TSA	Furan hot box	Phenolic hot box	Shell
Carbon monoxide (30 min)	A	A	A	A	A	A	A	A	A	A	A	A
Carbon dioxide (30 min)	B	B	B	B	B	B	B	B	B	B	B	B
Sulfur dioxide	B	B	C	C	C	C	A	B	B	C	C	B
Hydrogen sulfide	B	B	C	C	C	C	B	B	B	C	C	C
Phenols	B	C	C	C	C	B	B	C	C	C	C	C
Benzene	B	B	B	B	B	B	B	C	B	B	B	B
Toluene	B	C	C	C	B	B	B	C	B	C	C	B
Meta-Xylene	C	C	C	C	B	B	C	B	B	C	C	C
O-Xylene	C	C	C	C	B	B	C	B	C	C	C	C
Naphthalene	C	C	C	C	C	C	C	C	C	C	C	C
Formaldehyde	C	C	C	C	C	C	C	C	C	C	C	C
Acrolein	C	C	C	C	C	C	C	C	C	C	C	C
Total aldehydes (Acetaldehyde)	C	C	C	C	B	C	B	C	B	C	C	C
Nitrogen oxides	B	C	C	C	B	C	C	C	B	B	B	C
Hydrogen cyanide	C	C	C	C	B	B	C	B	B	B	B	B
Ammonia	C	B	C	C	C	C	C	C	B	A	A	B
Total amines (as Aniline)	C	C	C	C	C	B	C	C	B	B	B	B

A = Chemical agent present in sufficient quantities to be considered a definite health hazard. Periodic monitoring of concentration levels in workplace recommended.

B = Chemical agent present in measurable quantities, considered to be a possible health hazard. Evaluation of hazard should be determined for given operation.

C = Chemical agent found in minute quantities--not considered a health hazard under conditions of use.

Adapted from reference [72]

TABLE III-3. Airborne emissions from chemically-bonded thermosetting systems during mixing, molding, and coremaking*

Chemicals	Core oil	Furan hot box	Phenolic hot box	Shell	Carbohydrate
Carbon monoxide	?	?	?	?	?
Formaldehyde	0	?	X	X	?
Hydrogen cyanide	0	0	0	?	0
Ammonia	0	0	0	X	0
MDI	0	0	0	0	0
Sulfur dioxide	0	0	0	0	0
Hydrogen sulfide	0	0	0	0	0
Phenols	?	0	?	?	0
Benzene	?	?	?	?	0
Toluene	?	?	?	?	0
Furfuryl alcohol	0	?	?	0	0
Methanol	0	?	?	0	?

*NOTE: Assuming normal ventilation, optimized binder usage, and proper handling of binder system.

? = Possibly present in working environment--depending upon specific formulation and sand quality.

0 = Not expected to be present in sufficient quantities to be considered a health hazard.

X = Present in sufficient quantities to be considered a possible health hazard.

Adapted from reference [74]

TABLE III-4. Airborne emissions from chemically-bonded "no-bake" systems during mixing, molding, and coremaking*

Chemicals	Furan no-bake H_3PO_4(PA)	Furan no-bake (TSA)	Phenolic no-bake (TSA)	Alkyd urethane	Phenolic urethane	Sodium Silicate (carbon dioxide or ester)
Carbon monoxide	0	0	0	0	0	0
Formaldehyde	?	?	X	0	?	0
Hydrogen cyanide	0	0	0	0	0	0
Ammonia	0	0	0	0	0	0
Aromatic amines	0	0	0	?	?	0
MDI-Isocyanates	0	0	0	0	0	0
Sulfur dioxide	0	0	?	0	0	0
Hydrogen sulfide	0	?	?	0	0	0
Phenols	?	?	X	0	?	0
Benzene	0	?	?	0	0	0
Toluene	0	?	?	0	?	0
Furfuryl alcohol	?	?	0	0	0	0
Methanol	0	?	?	0	0	0

*NOTE: Assuming normal ventilation, optimized binder usage, and proper handling of binder system.

0 = Not expected to be present in sufficient quantities to be considered a health hazard.
? = Possibly present in working environment--depending upon specific formulation and sand quality.
X = Present in sufficient quantities to be considered a possible health hazard.
TSA = Toluene sulfonic acid.
PA = Phosphoric acid.

Adapted from reference [74]

blood dyscrasias, convulsions, ventricular fibrillation, chromosomal aberrations, aplastic anemia, and leukemia. Acute exposure may result in CNS depression and skin irritation [58,78]. Because benzene may induce progressive malignant disease of blood-forming organs (leukemogenic), NIOSH has designated benzene as a carcinogen [78]. Xylene and toluene may be used as solvents in core wash materials [69]. Exposure to high concentrations of toluene may result in impaired muscular coordination and reaction time, mental confusion, irritation of the eyes and mucous membranes, and transient liver injury [58,61,79]. Exposures to high concentrations of xylene may produce CNS depression, minor reversible liver and kidney damage, corneal vacuolization, and pulmonary edema [58,80].

(4) Chlorine

Chlorine (Cl_2) used as a degassing agent with nonferrous alloys, mostly aluminum, is extremely irritating to the eyes and respiratory tract. In acute, high concentration exposures, Cl_2 acts as an asphyxiant by causing cramps of the laryngeal muscles; pulmonary edema and pneumonia may develop later [58,61,81].

(5) Diphenylmethane Diisocyanate (MDI)

Polymeric polyisocyanates (of the MDI type) are used in urethane cold-box and no-bake binder systems. Inhalation exposure is most likely to occur during pouring, cooling, and shakeout. MDI is irritating to the eyes, respiratory tract, and skin and may produce bronchitis or pulmonary edema, nausea, vomiting, and abdominal pain. Sensitization may occur under high exposures and may cause an asthmatic reaction [58,82].

(6) Formaldehyde and Other Aldehydes

Formaldehyde may be combined with urea, phenol, or furfuryl alcohol to form resinous binders used in shell, hot-box, and no-bake coremaking and no-bake molding [15,83]. Formaldehyde is also a constituent of resinous binders used for phenolic urethane and furan-sulfur dioxide (SO_2) cold-box processes.

Formaldehyde and other volatile aldehydes are strong irritants and potential sensitizers to the skin, eyes, and respiratory tract. Short-term exposure to high concentrations may produce pulmonary edema and bronchitis. Contact dermatitis and allergic sensitization may also develop [58,84]. Formaldehyde is designated a potential human carcinogen by NIOSH [85].

(7) Furfuryl Alcohol

Furfuryl alcohol is added to urea-formaldehyde resins to form a modified furan resin in hot box coremaking and is the feedstock for formulating furan no-bake binders [13]. Exposure to furfuryl alcohol may result in lacrimation, bronchitis, mild sore throat, and allergic contact dermatitis [86].

(8) Hexamethylenetetramine

Hexamethylenetetramine (Hexa) is used as a curing agent and catalyst in shell molding [13,15,69]. It is a mild skin irritant. Side effects from ingestion include urinary tract irritation, digestive disturbances, and skin rash [58].

(9) Polycyclic Aromatic Hydrocarbons (PAH's)

Polycyclic Aromatic Hydrocarbons (PAH's) such as benzo(a)pyrene, naphthalene, and perylene are produced by low-temperature, destructive distillation during pouring of iron into green-sand molds [13,22]. Coal-tar fractions containing mixed PAH's have been shown to be carcinogenic when applied to the skin of experimental animals [87], and benzo(a)pyrene is considered to be a human carcinogen [88]. High naphthalene exposure may result in erythema, dermatitis, eye irritation, cataracts, headache, confusion, nausea, abdominal pain, bladder irritation, and hemolysis [58].

(10) Sulfur Oxides and Hydrogen Sulfide

Sulfur dioxide (SO_2) and other sulfur oxides may be formed when high sulfur content charge materials are added to furnaces, usually cupolas [22,69]. Sulfur dioxide is found as an emission during magnesium casting [89], in some core-curing operations, and in the sulfur dioxide-furan cold-box processes [15,69]. Gaseous sulfur dioxide has a strong suffocating odor. Long-term chronic exposure may result in chronic bronchitis and severe acute over-exposure may result in death from asphyxiation. Less severe exposures have produced eye and upper respiratory tract irritation and reflex bronchoconstriction [58,61,69,90].

Hydrogen sulfide (H_2S) can be formed from water quenching of sulfurous slag material. Catalysts based on arylsulfonic acids used in phenol-formaldehyde and furan binders also produce SO_2 and H_2S emissions during pouring [15,75]. Hydrogen sulfide exposures can produce eye, respiratory tract, and lung irritation; headache; dizziness; sensory impairment; sleep disturbance; loss of appetite; and death from paralysis of the respiratory centers in the brain [58,61,91].

2. Physical Hazards

a. Noise

The NIOSH criteria document on noise [92] states that exposure to daily noise levels above 90 dBA for an 8-hour time-weighted average

(TWA) may cause hearing loss and, may trigger changes in cardiovascular, endocrinologic, neurologic, and other physiologic functions. Hazardous noise levels are produced in many foundry operations, with levels over 105 dBA's being recorded near tumbling mills, arc furnaces, molding machines, sand shakeout, grinding, and combustion flame areas [7]. In addition to the possibility of temporary or permanent hearing loss, high noise levels may cause difficulty in verbal communications and in hearing warning signals or emergency commands.

b. Vibration

Foundry workers may be subject to whole-body vibration from shakeout, sand-slinging, forklift trucks, conveyors, overhead cranes, pneumatic ramming tools, and jolt-squeeze machines. Hand-arm, or segmental, vibration occurs from using hand-held power grinders, chippers, and other pneumatic tools [7,93,94].

Whole-body vibration may induce increased pulmonary ventilation and oxygen consumption, increased gastric secretions and intestinal motility, and marked changes in skeletal structure [58]. Hand-arm vibration is a more localized stress that may result in Raynaud's phenomenon otherwise known as Vibration White Finger. Symptoms include blanching and numbness in the fingers; decreased sensitivity to touch, temperature, and pain; and loss of muscular control. Chronic exposure may result in gangrenous and necrotic changes in the finger [58,95].

c. Heat

Both radiant and convective heat generated in the foundry during the melting and pouring of metal creates a hot environment for these and other foundry operations. The heating of molds and cores and the preheating of ladles are additional heat sources. Workers engaged in furnace or ladle slagging and those working closest to molten metal, including furnace tenders, pourers, and crane operators, experience the most severe exposures [7,48]. Molten metal and hot surfaces that exist in foundry operations create a potential hazard to workers who may accidentally come in contact with hot objects. Besides the direct burn hazard caused by hot objects, environmental heat appears to increase the frequency of accidents in general [96].

During the first week or two of heat exposure, most, but not all, healthy workers can become acclimatized to working in the heat. However, acclimatization can also be lost rather rapidly; a significant reduction in heat acclimatization can occur during a short vacation or a few days in a cool environment [58,97]. The health effects of acute heat exposure range in severity from heat rash and cramping of the abdominal and extremity muscles, to heat exhaustion, heat stroke, and death. Chronic exposure to excessive heat may also result in behavioral symptoms such as irritability, increased anxiety, and lack of ability to concentrate [58,97].

d. Nonionizing Radiation

Both ultraviolet (UV) and infrared (IR) radiation pose potential health hazards, especially to the skin and eyes. Radiation from molten metal around cupolas and pouring areas and the arc in electric furnaces can produce inflammation of the cornea and conjunctiva, cataracts, and general skin burns [2,58,98]. Other problems associated with exposure to UV radiation can include synergistic interactions with phototoxic chemicals and increased susceptibility to certain skin disorders including possible skin cancer [58,98]. UV radiation is also present in other foundry operations such as welding and arc-air gouging.

IR radiation from molten metal may produce skin burns and contribute to hyperthermia. Although there is no evidence that IR alone will cause cancer, it may be implicated in carcinogenesis induced by some other agents [99].

C. Epidemiologic and Other Foundry Studies of Adverse Health Effects

1. Respiratory Disease in Foundry Workers

The most commonly reported respiratory disorder among foundry workers who are exposed to crystalline silica and mixed dust exposures is pneumoconiosis. Also, the incidence of bronchiogenic lung cancer is believed to be higher among foundry workers.

a. Pneumoconiosis

The term, pneumoconiosis, literally means dust in the lungs. However, because not all dusts deposited in the lungs will result in recognized lung diseases, pneumoconiosis has been given medically significant definitions which have differed somewhat with time. In the 1965 24th edition of Dorland's Illustrated Medical Dictionary pneumoconiosis is defined as, "a chronic fibrous reaction in the lungs to the inhalation of dust." In the 1981 26th edition, the definition was expanded to, "a condition characterized by permanent deposition of substantial amounts of particulate matter in the lungs, usually of occupational or environmental origin, and by the tissue reaction to its presence." The 1981 revision better defined the deposition of particulate matter (dust), in which not all types of dust lead to significant fibrotic lung tissue reactions. Based on the type of deposited particulate matter, the nononcogenic lung tissue response can be divided into fibrotic, nonfibrotic, or mixed tissue reactions [58]. The general category of pneumoconiosis is also divided according to the dust involved, e.g., silicosis (silica), siderosis (iron), asbestosis (asbestos), coal workers pneumoconiosis (coal), berylliosis (beryllium), and byssinosis (cotton dust).

The clinical diagnosis of pneumoconiosis is based mainly on: (1) the history of exposure; (2) the symptomatology; (3) the lung x-ray findings; and, (4) pulmonary function tests [58]. None of these approaches provide sufficient information for diagnosing a specific type of pneumoconiosis; therefore, radiographic evidence and the history of exposure are fundamental for a diagnosis [58,100].

For the chest x rays to be useful, it is necessary that a standard classification of radiographic changes be adopted and utilized in all clinical studies. This was not the case in the past. Not until the International Labor Organization (ILO) U/C classification was adopted in 1972 has a simple reproducible system for recording radiographic changes in the lungs been available [58,60,101]. The most recent ILO U/C classification system is the 1980 ILO version [102].

The lack of a standard system for describing radiographic changes in lung structure has made it difficult to compare data presented in early studies of pneumoconiosis in foundry workers with the data presented in recent studies.

Silicosis is the most prevalent and the most serious of the fibrogenic pneumoconioses seen in foundry workers. Its pathogenesis and pathology are not different from the silicosis found in any other group of workers exposed to excessive levels of respirable free silica. The primary causative agent is crystalline silica dust deposited in the lungs [54,56,58,61]. The severity of the fibrotic response in silicosis is generally proportional to the level of fine respirable silica dust exposure and the number of years of exposure [54,56,100,103].

Early studies of pneumoconioses in foundry workers provided the basis for worker compensation for pneumoconiosis in the industry both in the United States and abroad. In 1923, Macklin and Middleton [27] reported the first large-scale investigation in England of chest disorders in foundry workers. Based on clinical examinations of 201 steel casting dressers surveyed, 22.8% had pulmonary fibrosis. At that time, fettling or cleaning was done mainly with hand tools rather than with pneumatic tools, and the authors emphasized that even then fettlers were exposed to large amounts of dust. Later, the use of pneumatic tools created more dust, increasing the potential for silicosis among fettlers [56].

Because of an expanding awareness of the problem of silicosis among foundry workers in the United States, several studies on pulmonary fibrosis in foundry workers were carried out (Table III-5). In addition to these compensation studies, other studies were done in the United States and abroad to evaluate workers' health in individual foundries.

In other studies [104,297], only workers with the longest periods of exposure were selected. These early studies varied greatly not only in the numbers of workers examined but also in the types of foundries observed. In some investigations, only workers employed in a specific foundry occupation, such as cleaning of castings, were

TABLE III-5. Prevalence rates for pulmonary fibrosis as reported in early studies of foundry workers

Year of report	Investigators	Location of study	Type of foundry	Numbers of workers examined	Percent of workers with pulmonary fibrosis		Ref.
					diffuse	nodular	
1931	Komissaruk	Austria	Iron	40	N/A	30	[104]
1933	Landau	Germany	Iron, steel	126	N/A	69	[105]
1934	McConnell and Fehnel	Wisconsin	Iron, steel	210	13.3	31.4	[297]
1934	Pope and Zacks	Massachusetts	Not stated	Not stated	11.4	N/A	[103]
1935	Warfield	Wisconsin	Iron	691	N/A	17.5	[106]
1936	Kuroda	Japan	Steel	314	26	8	[107]
1937	Osmond	Pennsylvania	Iron, steel	686	15.1	10.1	[108]
1937	Kelley and Hall	New York	Not stated	N/A	7.5	1.2	[100]
1938	Sander	Wisconsin	Iron, steel	4,035	N/A	7.0	[109]
1938	Trice and Easons	North Carolina	Iron, steel, nonferrous	546	8.2	1.0	[110]
1938	Greenburg, Siegal, and Smith	New York	Iron	1,960	4.7	3.7	[111]
1939	Sander	Wisconsin	N/A	8,377	21.0	5.8	[112]
1942	Brown and Klein	U.S.	Steel nonferrous	454	3.7	2.4	[113]
1945	Keatinge and Potter	Britain	Iron	60	22	N/A	[114]

N/A - Not available

Adapted from references [56,115]

examined [27,105,116]. Some studies did not include chest x rays; for example, Macklin's findings [27] were based on clinical examination alone. In other studies, x rays were not taken of the entire study population; Kuroda [107] x rayed only 314 of the 715 workers examined. In some cases, the population studied was small; Komissaruk [104] examined 40 workers in one foundry.

In evaluating the data and comparing the findings of these early studies, variations in x-ray techniques and classifications must be considered, especially in the borderline cases. The reported prevalence in foundry workers of what was variously labeled as fibrosis, a term used for different lung structure appearances, varied from 1.5 to 24%; the reported prevalence of stage I silicosis varied from 1 to 40%; and the presence of stage II and III silicosis varied from 1 to 65%. These and other studies carried out in 13 different countries reported the presence of silicosis in foundry workers [56]. It must be concluded from these early studies that foundry workers throughout the world suffered from dust diseases of the lungs and that certain foundry jobs (e.g., shakeout and cleaning castings) were more hazardous as judged by the prevalence, severity, and complication of lung diseases. The highest incidence of silicosis, ranging from mild to severe and disabling was found among casting cleaners [27,56,105,106,108,109,111,115,117].

In 1950, two major studies of pneumonconiosis in foundry workers were published, one in Great Britain by McLaughlin [56] and the other by Renes et al. [115] in the United States. McLaughlin's report included the results of clinical, spirometric, and radiographic examinations of 3,059 workers (2,815 men and 244 women) in 19 foundries (iron, steel, and mixed iron and steel). Each x ray was viewed at least four times by each of three observers. By majority vote, the films were categorized as (I) normal, (II) early reticulation, (III) marked reticulation, or (IV) nodulation and opaque or massive shadows. A complete occupational history was taken, and a family history and previous health record were noted with particular reference to tuberculosis. The physical examination included measurement of the chest girth and expansion, exercise tolerance tests, and in one foundry, measurements of tidal air and vital capacity. In order to attribute prevalence rates to different environments, and thereby assess the risk of one occupational group against another, the data were standardized for age and length of exposure. Of the 244 women, 242 had normal chest x rays and for this reason they were omitted from the statistical analyses. When the data from all occupational groups for all foundries were combined, 71% showed no abnormal x-ray changes, 17% showed category II changes, 10% showed category III changes, and 2% showed category IV changes. However, when the data for the three categories of foundries, iron, steel, and mixed, were examined separately, steel workers showed a statistically higher prevalence ($p<0.001$) of category III changes (16%) than did the iron and mixed iron and steel workers (6%). The difference was calculated to be significant even when corrections were made for the differences in age and length of exposure in the three groups. For category II changes, the incidence data were similar for all three types of foundries.

When the workers were subdivided into the broad occupational groups of (1) molding shop workers, (2) fettling shop workers, and (3) other workers, the molding shop workers had a prevalence of severe x-ray abnormalities (x-ray categories III and IV) of 13% in steel foundry workers vs. 7% in workers in both iron and nonferrous foundries. For fettlers, the prevalence of severe x-ray abnormalities was 34% in steel foundries compared with 12% in iron and 13% in mixed foundries. The higher prevalence of the more severe x-ray abnormalities (categories III and IV) among steel workers for all occupations combined was essentially a feature of work in the molding and fettling shops, and of the two, the fettling shop operations were the most hazardous. Steel melt pouring temperature is higher than iron melt temperature and results in more sand fracturing and silica dust production.

The overall conclusions of the McLaughlin [56] study indicate that foundry workers are at a substantial risk of developing silicosis and lesser forms of pneumoconioses and that steel foundry workers are at higher risk than iron foundry workers. The most marked radiographic changes were most frequently seen in all workers in the fettling shops, mainly among fettlers, and shot blasters.

In 1950, Renes et al. [115] reported on a 1948 and 1949 survey conducted in 16 ferrous foundries which were considered representative of the 185 Illinois foundries surveyed. Occupational and medical histories were taken from 1,937 of the 2,000 workers employed in these foundries. Chest x rays of 1,824 workers were classified by the classification recommended at that time by the U.S. Public Health Service (PHS). Significant pulmonary fibrosis of occupational origin was identified in 9.2%; 7.7% were ground glass 2 stage (classification D) and 1.5% nodular (classifications E, F, and G). Nodular pulmonary fibrosis occurred with about equal frequency in the steel and gray iron foundrymen. The classification O, and E, F, and G are roughly comparable to the "ground glass" and "nodular" classes (See Table III-6). In general, it required 14 or more years of exposure to develop nodular silicosis in the foundry industry. The prevalence of nodular silicosis was 0.1% under 10 years of exposure, 1% for 10-19 years, and 5% for 20 or more years of exposure. The only diagnosis greater than nodular stage 1 was in the group with 20 years or more exposure. In this long-exposure group, an additional 20.9% showed ground glass 2 changes. Symptoms were considered to be of minor significance in the instances of pulmonary fibrosis observed in this study. Nodular pulmonary fibrosis occurred predominantly among the molders in the gray iron foundrymen and among the cleaning and finishing workers in the steel foundrymen.

The Renes et al. and the McLaughlin studies [56,115] had certain similarities in numbers and types of foundries surveyed. These two studies remain among the best in regard to the interpretation of radiographic findings. They both have used two or more x-ray readers and have recognized the problem of intra- and inter-observer variation.

The "categories" of the British survey [56] and "classifications" of the U.S. survey [115] are not strictly comparable as shown in Table III-6. Age and length of exposure would have to be taken into account for a more meaningful comparison of incidence of x-ray abnormalities.

Most of the early studies on the hazards of foundry work have related mainly to ferrous foundries; some of the larger studies do not specify the foundry types. Greenburg [111] x rayed 347 workers in 17 nonferrous foundries and found that 2.2% had fibrosis and 2.8% had silicosis vs. 4.7% and 2.7% in iron foundry workers and 5.5% and 3.7% in steel foundry workers. Of the 215 foundry workers x rayed by McConnell and Fehnel [297], only five were employed in nonferrous foundries; one x ray showed nodulation and one showed fibrosis. In both cases, the worker was employed in the molding department.

In 1959, Higgins et al. [118] described the results of a random sample of 776 men in Staveley, England, including 189 foundry workers or former foundry workers. The workers were divided into two age groups: 25-34 and 55-64 years of age. No reason was given by the investigators for selecting only these two age categories. Based on radiographic evidence, 23% of the foundry workers 55-64 years of age had pneumoconiosis, while none of the workers in the 25-34 age group had pneumoconiosis.

In 1970, Gregory [119] reported an analysis of chest film surveys conducted from 1950 to 1960 of about 5,000 workers employed in steelworks in Sheffield, England, of which 877 were employed in one large steel foundry. Medical surveillance was conducted during the last 6 years of the 10-year study. Pneumoconiosis was diagnosed based on chest x rays and occupational histories. During the 6 years from 1954 to 1960, the prevalence rate of silicotic nodulation in all steel foundry workers was 6.4%. A higher prevalence rate for pneumoconiosis was found in workers in the fettling shop (14.7%) than in workers in the main foundry area (2.0%). The average time of exposure to crystalline silica before the development of nodulation was about 31 years for workers in the fettling and grinding shops and 36 years for workers employed in the main foundry. Workers exposed to crystalline silica before the age of 25 averaged a longer period at work before showing nodulation (36 years at work) than did workers who were first exposed after 25 years of age (23 years at work). The author was unable to relate the observed development of pneumoconiosis to specific exposure levels.

TABLE III-6. Interpretation of x-ray abnormalities

McLaughlin		Renes	
Categories	Results (%)	Results (%)	U.S.P.H.S classification
I (Normal)	71	68.2	A, B (normal, linear exaggeration 1 and 2)
II (Early reticulation)	17	21.6	C (ground glass one)
III (Reticulation)	10	7.7	D (ground glass two)
IV (Nodulation and/or massive shadows)	2	1.5	E, F, G (nodulation, conglomerate masses)

A,B = No definite sign of dust exposure
C = First degree ground glass appearance
D = Second degree ground glass appearance
E,F,G = Disseminated coalescence nodules and increasing size of conglomerate shadows

Adapted from references [56,115]

However, it was noted that the average time of exposure before the development of silicotic lesions seemed to be increasing, suggesting some gradual improvement in foundry environmental conditions.

In 1971, Davies [33] reported on respiratory disease among British foundrymen, including the prevalence of pneumoconiosis. The 2,427 foundries were divided into four categories: those estimated to employ 1-9, 10-49, 50-249, or >250 workers. A sample of 1 in 40 of each foundry size group was selected using tables of random sample numbers. The 66 selected foundries employed a total of 1,997 foundry workers, of whom 1,780 (93%) were included in the study; they were matched for age, height, and weight with 1,730 other factory workers used as controls. However, chest roentgenograms were obtained on only 1,308 foundry floormen, 352 fettlers, and 321 from the nonfoundry group. Of the foundry workers, 1,015 foundry floormen and 179 fettlers were accepted as not having been exposed to dust except in a foundry, and they provide the roentgenogram data base. Chest x rays were taken on the nonfoundry workers only when clinical reasons warranted it. The roentgenograms were read by three experienced readers using the National Coal Board version of the ILO (Geneva 1958) Classification. Category I was accepted as evidence of the existence of obvious pneumoconiotic changes. Category I pneumoconiosis was found in 12% of the foundry floormen and 23% of the fettlers. In Category II, 1.3% of the floormen and 11% of the fettlers developed the disease. In Category III and above, the rates were 0.3% for foundry floormen and 0.6% for fettlers. The degree of pneumoconiosis was related to years of foundry work and to job classification. Although this study primarily investigated chronic bronchitis, the quality of its design and execution provides a good estimate of the prevalence of silicosis in foundry workers and it confirms the greater risk of silicosis for workers who clean castings.

In 1972, Clarke [32] reported on the examination of 1,058 retired male workers from a large iron foundry. There were 76 workers with x-ray signs of pulmonary silicosis (26 in grade 1 and 50 in grade 2). Of these 76 workers, nine had decreased physical ability and a forced vital capacity (FVC) that was less than 48% of the predicted values; three had lung cancer. No data were provided on the total population from which the 1,058 retirees were selected.

The earlier studies of pneumoconiosis in foundry workers were essentially prevalence surveys of radiographic abnormalities in the workers examined rather than in the entire population at risk. Several authors have commented on the practice of transferring workers who showed x-ray evidence of pneumoconiosis to less dusty work areas, thereby excluding them from later surveys and artificially reducing the observed prevalence [56,111,115,119].

Data on the progression in the severity of pneumoconiosis in individual foundry workers are sparse. Sander reported no visible progression over a period of 4 years [112]; Keatinge reported progression in only three cases over a 9-year period [114]; Gregory [119] suggested that even removal from exposure to crystalline silica dust did not necessarily prevent the development of silicosis. However, in general, survey data indicated a trend toward more severe x-ray abnormalities with increasing age, age at first starting foundry work, and the number of years of exposure [34,56,115,120]. Dust exposure data with which to correlate the trends were generally lacking.

The question of the progression of pneumoconiosis as expressed by lung x-ray abnormalities, with continued exposure in foundry workers, was the thrust of the study by the Subcommittee on Dust and Fumes of the British Joint Standing Committee on Health, Safety, and Welfare in Foundries [34,120]. In 1958, a chest x-ray survey of iron foundry workers was conducted [120]. In 1968 the foundry workers from the same group who showed evidence of pneumoconiosis in 1958 were again given chest x rays.

Among the iron foundry workers who had chest x rays in 1958, 238 showed evidence of pneumoconiosis Category I (early reticulation) or above (11.5%). In the 1968 survey, the 1958 films were reexamined and all those showing Category I pneumoconiosis or above were selected for further study. The 176 selected cases were given a chest x ray and each pair of 1958 and 1968 films was compared to assess progression, if any, of pneumoconiosis during the 10 years of foundry work. Radiologic readings found that 48 of the 176 cases had progressed during the 10 years. The authors caution that the data "may provide a guide to the foundry population in general but it is unreliable in providing representative material when broken down into the (work category) groups used for this study" [34].

The amount of progression of pneumoconiosis was, in the above study, estimated "as the amount that a man's radiological pneumoconiosis would increase if he works for 10 years in the job." Progression was expressed as a "fraction of the width of Category I." The rate of progression cannot be used as an index of the severity of the pneumoconiosis. The rate of change differed between foundries and between jobs within the foundry. In general, the rate of progression was highest among the knockout and fettling workers who, on the average, progressed about one-third to one-half of an x-ray category in ten years. This translates into a progression of radiological reading of one category in 20-30 years (e.g., from category 1-0 to 2-0, or from 2-0 to 3-0 in 30 years).

Pulmonary function data, corrected for age and height on the workers studied in 1968, provided no evidence that early radiologic pneumoconiosis is associated with reduced ventilatory capacity. On the other hand, reduction in ventilatory capacity was associated with smoking history--being greatest in workers who smoked more than 15 cigarettes a day [34]. These studies support the observations that the prevalence of pneumoconiosis is associated with the foundry job category, the number of years of exposure, the age of the worker, and the age of the worker when starting foundry work. The rate of progression of radiologic pneumoconiosis is also probably associated with the same set of factors. Smoking cigarettes increases the risk of incurring pulmonary function impairment.

b. Chronic Bronchitis

The comparative assessment of the prevalence of chronic bronchitis among foundry workers in different countries and foundries is confounded by the varying diagnostic criteria and definitions used by investigators. In the past, the term "chronic bronchitis" usually meant any chronic respiratory or pulmonary condition associated with a cough and not ascribable to other recognized causes [33]. Some authors have been more specific in their definition by including sputum and breathlessness lasting over most of the year [119] or chest illness causing absence from work during the past three years [118]. The most recently accepted criterion for chronic bronchitis includes cough with phlegm which occurs on most days for at least three months a year for three consecutive years [121].

British national statistics indicate that foundry workers and miners have suffered an excess mortality and morbidity rate caused by bronchitis as compared with other workers. SMR's for bronchitis were also high for foundry workers' wives which suggests etiologic factors besides occupation [44,118].

In 1959 and 1960, Higgins et al. [118,122] published the results of a prevalence study of chronic bronchitis and respiratory disability in a 776-man (92% response rate) random sample of the 18,000 population of an English coal-mining and industrial town. An occupational and residential history and a respiratory symptom questionnaire were completed for each worker. Pulmonary function tests such as the forced expiratory volume in 0.5 second (FEV 0.5), maximum breathing capacity (MBC), forced vital capacity (FVC), and a chest x ray were obtained. The population studied was divided into two age groups, 25-34 and 55-64, for comparison of data. In age group 25-34, workers with no occupational exposure to dust had persistent cough and sputum in 16%, while in foundrymen the prevalence was 19%. For symptoms of chronic bronchitis, the prevalence was 2% and 6%, respectively. In age group 55-64, persistent cough and sputum were present in 32% of nondusty workers, 30% of foundrymen without pneumoconiosis, and 36% of foundrymen with pneumoconiosis. Mean MBC was 143 and 140 liters per minute (L/min) in the 25-34 year age group for nondusty trade workers and foundrymen, respectively. For the 55-64 year age group, MBC was 90 L/min for nondusty trade workers, 85 L/min for foundrymen without pneumoconiosis and 82 L/min for foundrymen with pneumoconiosis. The small numbers of subjects in some of the cells made statistical comparisons unreliable.

Although the results of the study are essentially negative, the care taken in the selection of the study population, the stratification of the random selection into age and occupation groups, and the comparisons made between the groups demonstrated the difficulties in the etiology of bronchitis.

Some other British investigators failed to demonstrate that foundry workers suffer a greater prevalence of chronic bronchitis than the general population in an industrial area [119,123].

In 1965, Zenz et al. [124] analyzed pulmonary function in three occupational groups employed in a diversified manufacturing company. Of the workers studied, 64 worked in the iron foundry, 61 were clerks, and 81 worked in the machine shop. All of the workers had a minimum of 20 years of service. Included in the pulmonary function analysis were tests for FVC, FEV_1, Maximal Expiratory Flow Rate (MEFR), and Maximal Mid-Expiratory Flow (MMF). No statistically significant differences in pulmonary functions were found between groups nor between smokers and nonsmokers in the three occupational groups.

Higgins et al. [118] reported a significant increase in the prevalence of persistent cough and sputum and decrease in MBC as related to the cigarette smoking experience in the group studied. For nonsmokers, light smokers, heavy smokers, and exsmokers, the prevalence of cough and sputum was 9, 22, 44, and 13%, respectively; grade 2 or over chronic bronchitis 4, 7, 8, and 13%, respectively; and MBC 145, 140, 133, and 143 L/min, respectively, in the 25-34 year age group. For the 55-64 year age group the prevalence was 3, 39, 52, and 21%, respectively, for cough and sputum and 3, 20, 22, and 13%, respectively, for chronic bronchitis. The MBC was 101, 87, 80, and 89 L/min, respectively.

In 1976, Koskela et al. [125] compared the prevalence of health problems in current and past employed foundry workers. A questionnaire was completed by 1,576 current foundrymen, 493 workers whose foundry employment terminated after they had worked for at least 5 years, and 424 workers who had worked in foundries for less than 1 year. The frequency of chronic bronchitis was similar among both current and former foundrymen: 16 and 14%, respectively, in nonsmokers; 29 and 23%, respectively, in smokers with slight or medium dust exposure; and 28 and 31%, respectively in smokers with high dust exposure. The authors concluded that chronic bronchitis was associated with exposure to dust among the current foundrymen and that chronic bronchitis may be a reason why older (55-64 years) workers leave foundry work. Results from the pulmonary function tests indicated that smoking was a major factor in the reduction in lung function.

In the Davies study [33], the "sputum-breathlessness" syndrome was found to be significantly more prevalent in foundry workers than in the control group of engineering factory workers (25% of foundry floormen, 31% of fettlers, and 20% of control workers). However, when the prevalence is standardized for smoking history, the prevalence was 20% for foundry floormen, 22% for fettlers and 22% for the control engineering factory workers. The prevalence ratio of the "sputum-chest illness" syndrome among nonsmoking foundry workers was 2.5 times that in the nonsmoking control workers. However, when the heavy smokers are compared, the ratio falls to 1.2. The prevalence ratio of "sputum-chest illness" syndrome increased with the number of years of foundry employment to approximately 1.58 after 15 years of foundry work as compared to the control group. Prevalence of this syndrome increased with smoking history in all the groups studied, and the combination of foundry work and smoking gave the highest prevalence rate.

In 1974, Mikov [126] reported the results of a retrospective investigation of the prevalence of respiratory symptoms, including chronic bronchitis, among the workers in five nonmechanized foundries in the Province of Vojvodina, Yugoslavia. The definitions and criteria of the Commission for the Aetiology of Chronic Bronchitis of the MRC were used. A completed questionnaire on respiratory symptoms, complete clinical examinations, and chest x rays were obtained. The data from the 535 workers studied (95% response rate) were matched with those from a control group consisting of 244 workers who worked at other jobs in the workshop but who did not experience unusual exposure to airborne pollutants in the working environment. The two groups were carefully matched for social and economic status (but not for smoking history). The prevalence of chronic bronchitis among the foundry workers was 31.03%, while the control group had only 10.26% ($p<0.001$).

The epidemiologic data do not prove a clear relationship between chronic bronchitis and foundry exposure. In 1971, at the ILO International Conference on Pneumoconiosis--IV in Bucharest, Rumania a working group concluded that "occupational exposures to dust may also be one factor among several more important ones in the aetiology of chronic bronchitis. In the present state of our knowledge there is insufficient evidence that chronic bronchitis may be considered an occupational respiratory disease of workers exposed to dust" [101].

A possible explanation for the apparent divergence of findings between different investigators may be their failure to clearly state whether they were discussing chronic simple bronchitis (chronic mucus hypersecretion) or chronic obstructive bronchitis (chronic airway obstruction). Parkes concluded that there is evidence that chronic simple bronchitis is related to the inhalation of dust and some toxic gases, but there is no evidence that chronic obstructive bronchitis is directly or consistently attributable to such exposures in foundries [121].

c. Lung Cancer

Evidence for an increased risk of lung cancer among foundry workers has been derived mainly from mortality data. These data may contain several serious problems such as (1) death certificates and autopsy reports that may contain only the record of occupation at the time of death and may not reflect previous occupations and their associated exposure to potential cancer producing substances and (2) smoking histories are usually lacking. The potential bias introduced in epidemiologic studies by different smoking behavior may be substantial since it has been estimated that the incidence of lung cancer in men would be significantly reduced in the absence of cigarette smoking [47]. In evaluating the lung cancer risk studies, the positive and negative biases inherent in such studies must be kept in mind.

The Registrar General's study from 1930-32 summarized by Doll in 1959 [43] reported that, in England and Wales, "metal molders and coremakers" (SMR=155, observed 158), and "iron foundry furnacemen and laborers" (SMR=142, observed 17; SMR=131, observed 136, respectively) ranked fourth and fifth in the list of occupations with the highest mortality rates from lung cancer. The highest death rates for lung cancer among the workers in Sheffield, England were reported to occur among foundry workers, smiths, and metal grinders [45]. It was suggested that iron in certain forms might promote the development of cancer [127,128].

The results of two series of autopsy studies reported by McLaughlin [56] and McLaughlin and Harding [42] showed a higher-than-expected frequency of lung cancer among ferrous foundry workers, many of whom also had accompanying siderosis. An overall prevalence at death of 10.8% of carcinoma of the bronchi was much higher than would be expected from the prevalence in the general population. The authors speculated that mineral oil, soot, crystalline silica, and fumes resulting from the pyrolysis of organic oils and binders in the foundry environment may have contributed to the increased incidence of lung cancer in the workers studied.

With respect to crystalline silica, very little has been established regarding the role of quartz containing dusts in the induction of lung cancer in foundry workers, primarily because exposure to such dusts is frequently concomitant with exposure to low concentrations of volatile carcinogens such as polyaromatic hydrocarbons (PAH) or other suspect carcinogens, e.g. chromium and nickel, that are found in foundry atmospheres. While data presently available from human exposures indicates that exposure to crystalline silica dusts alone does not lead to an increased incidence of lung cancer. Thus, until adequate human studies show otherwise, it is prudent to recommend avoidance of exposure by foundry workers to combinations of crystalline silica dusts and any concentration of airborne carcinogens, known or suspect [129,130].

Estimates of lung cancer prevalence rates based on selected cases among workers employed in several industries were published in 1971. A prevalence of lung tumors among foundry workers of 9.6 tumors/1,000 workers vs. 4.7 tumors/1,000 in a nonindustrial population was based on seven such tumors in an unspecified population of foundry workers. The foundries from which the populations at risk were drawn included iron, steel, and brass. However, the author stated that no specific carcinogens or other contributing variables had been identified that could be associated with this cancer prevalence rate. Only the lung cancer incidence rates in the asbestos and chemical manufacturing industries and in asbestos and anthracite coal mining exceeded the incidence rate in the foundries [131].

In 1976, Koskela et al. [40] studied the mortality experience of 3,876 men from a total of 15,401 workers who had at least 3 months of exposure in 20 iron, steel, and nonferrous foundries randomly selected for the Finnish Foundry Project. The age-adjusted mortality rate of foundry workers approached the expected level, with an SMR of 90 for all foundry workers and 95 for workers in typical foundry occupations, these slight deficits may in part be explained by the healthy worker effect. However, the lung cancer mortality for the entire group was higher than expected with an SMR of 175 (21 observed vs. 12 expected, $p<0.05$). The excess lung cancer deaths were confined to iron foundry workers, especially those with more than five years of exposure (SMR 270 $p<0.05$). Of 21 lung cancer cases, only one had never smoked; but the questionnaire suggested that the smoking habits of foundry workers were similar to those of the general population. The authors concluded that perhaps the foundry environment contained carcinogenic agents which require smoking as a cocarcinogen.

In 1977, Gibson et al. [30] described the results of a retrospective mortality study in which a group of 439 foundry workers employed in the foundry division of a Canadian steel mill was compared with 1,103 nonfoundry workers over a 10-year period beginning in 1967. Death certificates were obtained for all deaths in both groups, and each death was classified according to the International Classification of Diseases Adapted (ICDA). Total expected deaths in both groups was calculated from 1971 vital statistics for nearby metropolitan Toronto. Relative risk of lung cancer was significantly higher for foundry workers. The overall lung cancer SMR for foundry workers was 250 (8.4 expected vs. 21 observed). During this 10-year period, 21 of the foundry workers, or 4.8%, died of lung cancer, while 11 of the nonfoundry workers, or 1%, died of lung cancer. After age 45 a foundry worker was 5 times more likely to die of lung cancer than was a nonfoundry worker. Although the relative risk of dying from lung cancer was greater for foundry workers after the age of 45, the relative risk for total neoplasms and total deaths was not increased for foundry workers when compared with that for nonfoundry workers. In addition, there was a statistically significant ($p<0.005$) increase in lung cancer among foundry workers with more than 20 years of exposure to the foundry environment as compared with foundry workers with fewer years of work exposure. SMR's from lung cancer were calculated by work categories as follows: crane operators, 714 (4 observed vs. 0.5 expected); finishers, 314 (4 observed vs. 1.6 expected); molders, 255 (4 observed vs. 1.6 expected); coremakers, 208 (2.6 observed vs. 0.96 expected); and electric furnace/open hearth operators, 114 (3 observed vs. 2.7 expected). Environmental samples showed airborne particulate concentrations to be highest for the finishing jobs. The benzene-soluble fraction of total suspended particulates varied among job categories and could not readily be related to increased lung cancer. The authors stressed that the absence of smoking histories on the entire population was a serious deficiency. The smoking histories sampled in 1976 showed that 58% of the foundry workers smoked cigarettes compared with 53% of the nonfoundry workers. Of the 24 individuals in the lung cancer group on whom smoking histories were obtained, 22 (93%) were smokers.

Egan et al. [31] and Egan-Baum et al. [41] reported on mortality patterns from the death benefit records of the International Molders and Allied Workers Unions (IMAWU). To be eligible for death benefits a worker had to be a union member prior to 1961 and must have paid monthly union dues until death or until a life membership card was obtained. The death records included both active foundry workers and retired foundry workers. For each of the 2,990 death records for the years 1971-75 used in the study (99.2% of total), the underlying cause of death was classified according to the 8th International Classification of Disease Adapted (ICDA) classification. Smoking histories were not available for this decedent population. The age- and race-specific cause distributions of all deaths among males in the United States for 1973 were used as the standards from which expected deaths were calculated. Each comparison between observed and expected numbers of deaths was summarized as a PMR. The statistical significance of differences between observed and expected numbers of deaths was determined by a Chi-square test. Of the total number of deaths, 2,651 were white males and 339 were black males. The distribution of deaths by age in foundry workers, in contrast to the distribution of all deaths in the United States for males above age 30, showed a slight over-representation for above age 75 (45% vs. 38%) and an under-representation for under age 45 (7% vs. 15%). Death due to malignant neoplasms was associated with a PMR of 110 (545 observed vs. 497.65 expected) for white males and a PMR of 124 (86 observed vs. 69.29 expected) for black males, both of which were statistically significant increases ($p<0.05$). Cancer of the trachea and bronchus, and the lung, more than accounted for this by contributing 86 excess cases; a PMR of 144 (224 observed vs. 155.17 expected) was reported in white males and a PMR of 176 (39 observed vs. 22.10 expected) was reported in black males, both PMRs were significant increases ($p<0.01$). Also, nonmalignant respiratory diseases were significantly increased with a PMR of 138 (277 observed vs. 200.40 expected) in white males ($p<0.01$) and a PMR of 151 (30 observed vs. 19.81 expected) in black males ($p<0.05$). This latter observation was in large part attributable to a sixfold increase in pneumoconiosis with a PMR of 576 (30 observed vs. 5.21 expected) in white males ($p<0.01$) and a PMR of 1154 (3 observed vs. 0.26 expected) in black males (significance level not indicated due to small numbers). Additionally, in white males, while a decreased PMR of 73 was reported for the pneumonia and influenza death category, the remaining nonmalignant respiratory disease categories were associated with the following increased PMRs: "bronchitis" 140 (not significant), "emphysema" 159 ($p<0.01$) and "other respiratory diseases" 190 ($p<0.01$). These three categories for black males represented few deaths and therefore were not evaluated. Across all age groups, the PMR for heart disease was close to the expected, and mortality from nonmalignant respiratory diseases was higher than predicted for especially those over 65 years of age (PMR=144) with a moderate excess in persons 55-64 years of age (PMR=122). Excess lung cancer peaked at ages 60-64 (PMR=179).

In the most recent review of the epidemiologic literature on lung cancer in ferrous foundry workers, Palmer and Scott [47] concluded that there was a two- to threefold increased incidence of lung cancer associated with ferrous foundry work. The increased incidence was higher among the molders, casters, and cleaning room workers. The authors emphasized that these data reflect exposures that occurred years ago and that the cancer risk reflecting today's exposure may be quite different. The introduction of new foundry practices and molding materials could substantially change a specific foundry environment for better or for worse [47].

An apparent excess of lung cancer among foundry workers has been noted from a review of vital statistics [43,44,45], mortality studies [30,31,40,46], and other investigations [42,56,131]. The complexity and variety of foundry exposures, changing work forces, changes in work practices and molding materials, and inadequacy of occupational, medical, and smoking history documentation all hinder a definitive answer to the cause-effect relationship which the overall data on lung cancer in foundry workers strongly suggest.

Three recent review papers and one epidemiologic study support the earlier conclusions that the risk of lung cancer is increased in foundry workers [132,133,134,135]. In a 1983 review of the mortality experience of foundry workers, SMR's of between 147 to 250 were reported in nine different studies included in the review. In the four cohort studies included in the review, SMR's of approximately 200 were reported with one of the studies having an SMR of 250 [134].

In 1984 Fletcher and Ades [135] published the results of a study in which they followed the health experience of a cohort of male workers from England who had started foundry work between 1946 and 1965 and had worked in a foundry at least one year. The cohort was followed prospectively until 1978. Of the cohort group, 7,988 were traced and alive, 1,858 were traced and dead, 173 had left England, and 231 could not be traced. Of the 1,858 deaths, details of cause of death were available on all except 14. Observed and expected deaths were calculated and grouped by foundry, occupational category, and 5-year entry. No data on smoking habits of the cohort were collected. Mortality from lung cancer was increased among the foundry and fettling shop area workers (SMR's of 142 and 173, respectively, $p<0.001$). The authors commented that "the narrowness of the range of most of the risk estimates, approximately 1.5 to 2.5, is striking, as is the fact that of 12 investigations from which relative risk from lung cancer might be estimated for foundry workers, none of the risk estimates were close to or below unity."

2. Nonrespiratory Effects in Foundry Workers

a. Zinc Oxide

In 1969, Hamdi [136] observed 12 brass foundry furnace operators who had been subjected to chronic exposure to zinc oxide fumes. Ten unexposed subjects were also studied. Determinations of zinc (Zn) concentrations in the plasma, red blood cells, whole blood, and urine were made for each worker and control subject. Zinc concentrations were also determined in the gastric juices of eight workers and seven controls. No environmental data were reported. The author found a significant increase in Zn concentration in the red blood cells, whole blood, and fasting gastric juices of the exposed foundry workers as compared to the control group. The absorbed Zn appeared to be rapidly eliminated through the gastrointestinal and urinary tracts, with excess Zn being stored in the red blood cells. The author speculated that elevated Zn concentrations in gastric fluids in the exposed workers might account for the high incidence of gastric complaints reported [136]. However, there are no sufficient data to link Zn levels in body fluids to any specific system disorder [58,61].

b. Inorganic Lead

Although many epidemiologic studies on the health status of workers exposed to lead (Pb) workers have been made, few have included foundry workers. On the basis of blood analysis, Stalker found that 79% of 98 brass foundry workers examined showed excessive Pb absorption. For this study, a high concentration of Pb in the blood was defined as one greater than 70 micrograms per deciliter (μg/dl) whole blood [137]. By comparison, NIOSH in 1978 [138] determined that unacceptable absorption of Pb and a risk of Pb poisoning are demonstrated at levels >80 μg/dl of whole blood. Stalker analyzed the blood of 24 of the workers who had had urinary Pb values above 150 μg lead/liter of urine or stippled erythrocyte counts above 1,000 per million red blood cells. These workers had a blood Pb level of 120 μg/dl. Followup physical examinations of 75 of the foundry workers revealed that 50% exhibited symptoms indicative of a mild "alimentary type of lead poisoning." However, the kind and incidence of symptoms in a group of 25 workers with high urinary leads did not differ significantly from the group as a whole [137]. The most frequently occurring symptoms included excessive urination at night (nocturia), gingivitis, headache, constipation, vertigo, and weight loss.

Neurobehavioral effects of Pb exposure have recently been reported for 103 foundry workers. Sixty-one non-lead exposed assembly plant workers were used as the control group. The blood Pb levels in the foundry workers averaged 33.4 μg/dl (range 8-80) and 18.6 μg/dl (range 8.3-36) for the non-lead exposed group. Lead concentrations in the foundry and assembly plant air were not given. Neurobehavioral changes as measured by the Profile of Mood (POM) states were strikingly increased in the workers with blood Pb levels above 60 μg/dl. The foundry workers' POM scores, using the control group score as 100, were for those with blood Pb levels above 60 μg/dl, tension 155, anger 200, fatigue 135, depression 180, confusion 175 [139]. Blood Pb levels of over 60 μg/dl are considered to indicate exposure to unacceptably high levels of inorganic Pb. Normal blood lead levels range from 10-60 μg/dl [140]. The OSHA safety and health standard 29 CFR 1910, establishes an 8-hour TWA PEL for Pb of 0.05 mg/m^3 [141] and requires monitoring of blood Pb levels at least every 2 months for workers whose last blood sample indicated a blood Pb level at or above 40 μg/dl of whole blood.

c. Carbon Monoxide

Carbon monoxide (CO) is one of the most frequent contaminants in foundry air. In 1976, Hernberg et al., [142] surveyed 931 workers from a sample of 20 foundries for angina pectoris, electrocardiographic (ECG) changes, and blood pressure levels. Occupational and morbidity histories and smoking habits were obtained (53% were smokers). The prevalence of angina pectoris among the factory workers was increased over background for all workers, but was highest among smokers. The prevalence of angina for nonsmokers was 2% in workers without occupational CO exposure and 13% for those with CO exposure. For smokers the prevalence of angina was 15% for those without occupational CO exposure and 19% for those with CO exposure. Rate ratios failed to demonstrate a statistically significant increase in angina rate among nonsmokers due to CO exposure. The ECG showed no systematic increase in abnormality as a function of smoking and/or CO exposure. This may have resulted from the ECG's being taken while at rest and not under maximum CO exposure or levels of physical work; whereas the occurrence of angina pectoris was considered positive irrespective of whether symptoms had occurred under maximum work or conditions of CO exposure. Casters and furnacemen with CO exposure had higher systolic ($p<0.05$) and diastolic ($p<0.01$) blood pressures when compared to other occupational groups. When blood pressures of nonsmokers without occupational CO exposure were compared to blood pressures of smokers with occupational CO exposure, diastolic blood pressures were significantly higher ($p<0.05$) in those occupationally exposed to CO. The study did not include a nonfoundry control population; ECG's were taken only when workers were at rest; and heat, as a confounding variable, was not analyzed.

d. Beryllium

Beryllium (Be) and its compounds can be highly toxic [58,69,143]. The acute effects are mainly on the respiratory tract with cough, shortness of breath, and substernal pain. Chronic effects may become progressively more severely disabling with pulmonary insufficiency and right heart failure [58,143].

Although beryllium may be present in some foundries, its use is relatively limited. Air concentrations of Be were measured over a 7-year period in a modern copper-beryllium alloy foundry [144]. The general air and breathing zone concentrations of Be exceeded the NIOSH REL of 0.5 micrograms per cubic meter ($\mu g/m^3$) [98] and the American Conference of Governmental Industrial Hygienists (ACGIH) Threshold Limit Value (TLV®) of 2 $\mu g/m^3$ [88] in more than 50% of the air samples. However, no cases of chronic beryllium-induced disease were found [144]. Evidence for linking Be exposure to the development of a chronic respiratory disease (berylliosis) was reviewed by NIOSH with the conclusion that berylliosis would not occur at Be exposure levels at or below 2 $\mu g/m^3$ [143].

e. Chemical Binders

As a result of the strong evidence that foundry workers are at an increased risk from lung cancer, a search for carcinogenic or potentially carcinogenic substances in the foundry environment has recently been conducted. In particular, the polyaromatic hydrocarbons (PAH's) have been suspected.

Schimberg reported finding approximately 50 PAH compounds in the foundry air dust [145]. The benzo(a)pyrene (BaP) concentration in the air was much higher (mean 4.9, range 0.01-57.5 $\mu g/m^3$) in those foundries where a coal-tar sand-molding material was used than in those where a coal dust/sand mixture was used (mean 0.08, range 0.01-0.82 $\mu g/m^3$). The concentration of BaP also varied with the dust-particle size ranging from 0.3-5.0 $\mu g/m^3$ for dust >7.0 micrometers in diameter to 9.7-16.5 $\mu g/m^3$ for dust <0.5 micrometer.

Mutagenicity studies on material extracted from larger sized dust (>7.0 micrometers) showed relatively large direct acting mutagens with more of the indirect acting mutagen on the smaller sized dust (<1.1 micrometer). The authors concluded that the direct acting mutagens are other than PAH compounds and that BaP level is not a "reasonable marker for mutagenic activity" [145].

The emissions from four types of mold binders (furan, urethane, shell, and green sand) have been analyzed for the presence of carcinogens. They were analyzed for 16 metals, eight PAH's, and tive phenols. The PAH substances present in the highest concentrations in the water insoluble fraction were phenanthrene, benz(a)anthracene, and benzo(a)pyrene, with the concentrations lowest in the furan and urethane binders (0.6-230 μg/g) and highest with the shell and green-sand binders (200-7200 μg/g) [146].

In 1982, NIOSH [147,148] reported the levels of several airborne contaminants present in the core- and mold-making and metal-pouring areas of a steel-casting foundry. The diphenylmethane diisocyanate (MDI) concentrations ranged from below 0.042 to 0.173 ppb (0.43 to 1.77 $\mu g/m^3$) (average 0.082 ppb), all of which were far below the NIOSH REL of 50 $\mu g/m^3$; the formaldehyde concentration averaged 0.29 ppm (0.36 mg/m^3) with a highest value of 0.41 ppm (0.50 mg/m^3); dimethylethylamine (DMEA) concentrations ranged from 1.18 to 7.45 ppm (4.2 to 26.5 mg/m^3); trace metals were not present in significant amounts (ranging from none detected to 0.35 mg/m^3 for iron and 0.136 for manganese); CO averaged 82 ppm (94 mg/m^3) for metal skimmers, 50.6 ppm (58 mg/m^3) for pourers, and 9.6 ppm (11 mg/m^3) in the general pouring area--exceeding the NIOSH REL and the OSHA PEL for the skimmers and pourers; ammonia concentrations averaged 5.6 ppm (4 mg/m^3) in the coremaking area, hydrogen cyanide less than 0.9 ppm (1 mg/m^3), and aromatic amines below 1 mg/m^3; crystalline silica concentrations of 120 to 140 $\mu g/m^3$ were found in breathing-zone samples in the shakeout operations--exceeding the NIOSH REL of 50 $\mu g/m^3$ [147].

Concentrations of some contaminants in breathing-zone samples of air in the coremaking (shell, phenolic urethane, and bench processes) area of a foundry were included in a 1984 NIOSH Health Hazard Evaluation report [149]. The mean concentrations found were as follows: ammonia, not detectable; DMEA, 0.34 to 0.65 ppm (1.2 to 2.3 mg/m^3); formaldehyde, 0.24 to 0.73 ppm (0.3 to 0.9 mg/m^3); and acrolein, furfuryl alcohol, Hexa and MDI, none. Formaldehyde was the only one of the contaminants measured whose concentrations were considered potentially hazardous. Crystalline silica was not measured.

Crystalline silica content in dust was found in 116 Japanese foundries to average 16% of the 0.67 mg/m^3 of respirable dust. These levels were considered unacceptably high. Control measures would be required to reduce levels 140 $\mu g/m^3$ of respirable dust with not more than 13.6% crystalline silica to meet the Japanese acceptable environmental levels [150].

Ermolenko et al. [151] reported on the health of coremakers in the foundry of an automobile manufacturing plant in the U.S.S.R. Environmental data were also taken in two-binder system operations in which the coremakers used furfuryl-alcohol-modified carbamide-formaldehyde (KF-90) and phenol carbamide-formaldehyde (FPR-24) resins. Seven air contaminants were found within the breathing zones of those coreroom workers who operated single- and two-stage coremaking machines, who mixed sand for the process, or who finished the core. These contaminants were formaldehyde, methanol, furfural, ammonia, furfuryl alcohol, CO, and phosphoric acid. Concentrations of formaldehyde reached 1.2 ppm (1.5 mg/m^3) and methanol concentrations reached 3.97 ppm (5.2 mg/m^3) in areas where mixing of materials took place. Table III-7 shows mean concentrations of these compounds (ppm) at the breathing zones of workers who operated coremolding machines.

TABLE III-7. Mean air concentrations (ppm) for coremolding machine operators

	KF-90 binder		FPR-24 binder	
	Single-stage machine	Two-stage machine	Single-stage machine	Two-stage machine
Formaldehyde	5.0	1.8	3.7	2.7
Methanol	16.4	2.5	4.0	3.7
Furfural	0.13	0.008	0.05	0.01
Ammonia	8.9	2.4	1.4	0.43
Furfuryl alcohol	2.3	1.8	0.84	Not detectable
Carbon monoxide	Trace	10.9	Trace	10.9
Phosphoric anhydride (oxide)	0.02	0.01	N/A	N/A

N/A - Not available

Adapted from reference [151]

Except for formaldehyde, the breathing zone concentrations of the substances did not exceed any exposure standard or recommended guideline. Higher concentrations of emissions were present with the single-stage electrically heated core machines than with the two-stage gas-heated machines. The thin-walled single-stage cores probably underwent thermal decomposition and volatilization throughout rather than just on the external surface layer as with the two-staged cores. The gas flames may have helped burn the decomposition products as they evolved. The KF-90 binder may have produced higher concentrations of decomposition products because it has lower thermal stability and the formaldehyde used in its synthesis contained 5-11% methanol. Other sources for air contaminants included containers holding core rejects and inspection tables on which cores lay for cooling. Breathing zone levels of formaldehyde at those places averaged 3.7 to 2.7 ppm (4.5 and 3.3 mg/m^3) for the single- and two-stage machines, respectively, for binder FPR-24 and 6.2 and 2.2 mg/m^3, respectively, for the KF-90 binder [151].

Formaldehyde concentrations in the breathing zone of coremakers in many samples exceeded the OSHA PEL (8-hour TWA limit) of 3 ppm (3.7 mg/m^3), some exceeded the acceptable ceiling limit of 5 ppm (6.1 mg/m^3), and none exceeded the maximum 30-minute ceiling limit of 10 ppm (12.3 mg/m^3). Total daily exposure time was not given; consequently 8-hour TWA's could not be calculated [151].

To determine the effect of job-related factors on the Russian coremaker's health, 138 workers (125 women and 13 men) were examined and questioned for health effects (no control groups used for comparisons). Of these 138 workers, about half were under 30 years old and most had worked at their jobs from 1 to 5 years. Complaints included frequent throat inflammation (68%), nasal congestion (25%), dryness of nose and throat (20.4%), hoarseness (20.4%), and acute irritation of the upper respiratory tract (63%). Chronic rhinitis was present in 47%, chronic tonsillitis in 31.8%, and chronic pharyngitis in 18%. These studies illustrate some of the respiratory problems that may be associated with the use of chemical binders in the foundry industry. The breathing zone air concentrations of formaldehyde to which these workers were exposed ranged from 0.49 to 8.15 ppm (0.6 to 10 mg/m^3) [151].

Formaldehyde has been reported in sufficient quantities to be considered a health hazard in the phenolic hot-box chemically-bonded thermosetting core system and in the chemically-bonded phenolic no-bake process [152]. Since formaldehyde is considered to be a potential human carcinogen, engineering controls and work practices should be utilized to reduce exposure to its lowest feasible level [85].

Formaldehyde air concentrations at coremaking operations were reported for several NIOSH Health Hazard Evaluations conducted since 1972 [147,148]. Formaldehyde concentrations exceeding 1.0 ppm were found in 3 of 14 samples in one of the foundries (4.4, 10.6 and 18.3 ppm); in the other 11 samples the concentrations were less than 1 ppm (<0.02-0.57 ppm). In the other foundries, formaldehyde concentrations ranged from <0.02-0.73 ppm.

The phenolic, furan, epoxy, and other resins (and their thermal decomposition products) used as binders in hot-box and no-bake mold and other coremaking can cause contact dermatitis and allergic dermatosis [15,58,69]. Although a dermatitis or dermatosis can result from contact with a single substance, several factors are generally involved [153].

Adverse medical symptomatology was elicited from workers in the coreroom of a ferrous foundry as part of a NIOSH Health Hazard Evaluation [154]. The sand cores were produced either by heating the resin-coated sand or by the cold-box process. Automatic, electric-heated, and gas-fired core blow machines were in operation. At the time of the interviews, no adverse medical symptomatology such as eye and throat irritation was reported. However, symptoms typical of exposure to corebox gases and fumes (burning of the eyes, nose, and throat) were reported as having been experienced in the past.

f. Manganese

Foundry use of manganese (Mn) is mainly in iron and steel alloys and as an agent to reduce oxygen and sulfur content of molten steel [58,69]. Manganese dust and fumes may be a minor irritant to the eyes and respiratory tract. Chronic Mn poisoning can be an extremely disabling disease resembling Parkinsonism [58,155,156].

3. Thermal Stress and Strain

Foundry workers may be exposed to heat stress, particularly during the hot summer months. Thermal stress with Wet Bulb Globe Temperature (WBGT) levels of 30° to 50°C (80° to 122°F) have been measured in several foundry surveys [7,157,158,159,160]. At WBGT levels over 30°C the risk of incurring heat illness progressively increases [58,88,97,161,162], with the level of risk being higher for the heavier physical work. In those foundry studies where the level of physical work was measured, the 8-hour TWA metabolic rate was, for most jobs, 250 kcal/hr or less, which falls within the light to moderate physical work category [97,157,159,160]. This may account for the fact that heart rate, body temperature, sweat production, and fluid balance measurements on foundry workers have not indicated high levels of heat strain even when the environmental stress exposures were very high [157,159]. The amount of dehydration experienced by the foundry workers may approach critical levels [157,159,160]. Heat-related morbidity and mortality data on foundry workers are not available. An epidemiologic study of steel mill and foundry workers has implicated chronic heat exposure as a risk factor for cardiovascular and digestive disorders [163,164]. Even those who have worked at hot jobs with heat exposure below the ACGIH TLV [88] for 15 or more years had an increased incidence of digestive disease (excluding cirrhosis).

Several factors that may be involved in fatal heat stroke include relative obesity, dehydration, high environmental heat load, lack of acclimatization, and inadequate rest periods. Those working at hot jobs should be encouraged to take cooling breaks, drink sufficient liquids (water), and immediately report any feelings of not being well [165].

4. Auditory Effects

Noise levels during many operations in foundries are high and generally fall within the range of 85-120 dBA [7]. With proper engineering control and/or hearing protective devices, the actual exposure levels are usually below 90 dBA [7,166,167,168]. The noise levels at foundry operations without adequate engineering controls were found to be 108 to

433% above the OSHA PEL 8-hour TWA of 90 dBA [92]. The ACGIH TLV® of 85 dBA for an 8-hour TWA [88] was exceeded frequently even when engineering controls were in place [7].

Work stations in an integrated steel plant were monitored and studied by Martin et al. [166] to determine potential hearing loss among the foundry workers who were exposed to noise levels in the 85 - 90 dBA range. A total of 228 noise-exposed workers and 143 controls were tested. The average exposure noise level was 86 dBA for the slinger floor workers and 89 dBA for the electric furnace operators. The audiometers used in the testing were self-recording and manual types that conformed to ANSI Standard S3.6-1969 and were calibrated biologically and acoustically at regular intervals. The audiometer operator was a certified audio technician. The workers were tested at the start of the workshift to minimize temporary threshold shift effects. Workers were excluded for testing if they had worked in another noise area for more than three years, had more than a 40 dB hearing difference between ears at two or more frequencies (in which case only data from the better ear were used), or had been previously diagnosed for bilateral nonneurosensory hearing loss. The workers tested had not worn hearing protectors. The control group consisted of office staff workers having minimal occupational noise exposure. The workers tested were divided into four age groups of 18-29, 30-39, 40-49, and 50-65 years. A hearing level index (HLI) was computed as the average of the audiometric thresholds at 500, 1,000, and 2,000 Hertz (Hz). Hearing impairment was considered to have occurred when the HLI exceeded 25 dB. In general, the HLI increased with age (Table III-8), as also did the percentage of impairment (Table III-9). The "normalized" values showed that for electric furnace workers 50-65 years old, 32.5% had impaired hearing and that in slinger floor workers in this age group, 26.5% had impaired hearing compared with 10% of the controls.

The increased risk (percentage differences between the subject group and the control group) was 22.5% for the oldest electric furnace workers and 16.5% for the oldest workers on the slinger floor. These data indicate that an increase in hearing loss (corrected for age) can occur in some workers with occupational noise exposure in the dBA 85-90 range.

5. Chronic Trauma

In 1973, Mintz and Fraga [169] described eight cases of moderate-to-severe osteoarthritis of the elbow in foundry workers between 41 and 63 years of age who had been foundry workers for 8 to 21 years. Their work required the use of tongs 20 to 34 inches long to lift or twist metal rods, which produced large stresses and forces on the elbow joint. The main complaint was a limitation in the range of joint motion, rather than pain. The x-ray examinations revealed degenerative joint disease of the elbow. Similar changes in the elbow and wrist have been seen following prolonged use of pneumatic tools [170]. The observed changes were thought to be related to general stress and trauma at the joints rather than a specific foundry-related phenomenon.

TABLE III-8. Mean hearing level indices

Area	Age	Sample size	HLI	Statistically significant (p=0.05)
Floor slinger	18-29	25	9.4	S
	30-39	21	8.5	NS
	40-49	11	9.8	NS
	50-65	7	20.0	NS
Electric furnaces	18-29	23	7.8	NS
	30-39	16	8.7	NS
	40-49	12	12.1	NS
	50-65	13	21.4	S
Control Group	18-29	56	6.2	--
	30-39	36	8.4	--
	40-49	30	9.0	--
	50-65	21	10.5	--

S = significant
NS = nonsignificant
Adapted from reference [166]

TABLE III-9. Percentage with impaired hearing*

Area	Age	Sample size	% Impaired raw data	% Impaired "normalized"	Increased risk
Floor slinger	18-29	25	4.0 (1)	4.6	4.1
	30-39	21	0.0 (0)	1.8	0.3
	40-49	11	0.0 (0)	2.5	2.0
	50-65	7	42.8 (3)	26.5	16.5
Electric furnaces	18-29	23	0.0 (0)	4.0	3.5
	30-39	16	6.3 (1)	2.3	0.8
	40-49	12	16.7 (2)	15.5	11.0
	50-65	13	46.2 (6)	32.5	22.5
Control group	18-29	56	0.0 (0)	0.5	--
	30-39	36	0.0 (0)	1.5	--
	40-49	30	3.3 (1)	4.5	--
	50-65	21	4.8 (1)	10.0	--

*HLI >25 dB
Adapted from reference [166]

Partridge et al. [171] interviewed 858 male workers in six iron foundries for rheumatic complaints. Only workers actively involved in the production of metal parts and finished products were included. The observed prevalence of rheumatic complaints which increased with age among the floor molders was 61.5% (104 observed vs. 68 expected). Floor molders were the only group of foundry workers that had a significantly increased Standardized Complaint Ratio (SCR 153, $p<0.001$). Average worker absence due to rheumatic causes was 0.44 weeks/year; this was not different from that in other industries such as brewery, mining, and dock workers. Neither the levels of heat or cold nor psychological factors appeared to be related to the prevalence of rheumatic complaints, absence because of illness, or other complaints.

6. Vibration Syndrome

It has been recognized for some time that foundry workers, especially chippers and grinders, who use hand-held vibrating tools, may incur the clinical condition of "Vibration Syndrome," also known as "Raynaud's Phenomenon of Occupational Origin" or "Vibration White Finger." The symptoms may range from blue, cold fingers to necrosis and gangrene of the finger tissue requiring amputation of the affected parts [95,172,173].

Agate et al. [93] reported on a study of Raynaud's phenomenon among grinding room workers in a British foundry. Based on statements by the workers, 27 of 29 men and 5 of 8 women reported signs of Raynaud's phenomenon. Twenty-three of the 37 developed the phenomenon in both hands. The men affected were from 29 to 50 years old, with a mean age of 37; women were from 24 to 45 years old, with a mean age of 36. The time between starting grinding work and the onset of symptoms ranged from 0 to 7 years, with a mean of 1.75 years. All attacks occurred after exposure to cold conditions. The duration of attacks varied from 10 to 180 minutes, often lasting until the hands became warm. Disability in these workers, which was difficult to assess due to inadequate diagnostic methods, appeared minimal. In a few cases, 1-2 hours of work were lost while the hands were being warmed. When pain occurred, it was most often associated with the return of blood flow to the affected fingers. Of the 12 workers who had stopped grinding, three claimed no improvement after as long as 5.5 years. Nine claimed improvement to some extent, and one even had a cessation of attacks one year after stopping such work.

Cold water immersion test 59°F (15°C) induced pallor or cyanosis of the fingers in 21 cases, while 10 others who allegedly had the phenomenon showed no abnormal responses. The size of the grinding wheel used appeared to be related to the number of finger segments affected. Those workers using small wheels had a mean of 7.7 finger segments affected while those using larger wheels had 13.7 segments affected ($p<0.05$). The duration of employment, compared with the number of segments affected (index of severity), showed a significant degree of association (r=0.65, p=0.05). The study reported no preventive measures that could be effectively utilized. Some workers used gloves or strips of cloth, but most did not. This study demonstrated the presence of an annoying, and in some cases a mildly disabling, condition resulting from exposure to segmental vibration.

Leonida [94] reported on the occurrence of Raynaud's phenomenon among workers in an Illinois gray iron foundry. Of the 2,030 workers examined over a 16-month period, 107 of 123 who currently used hand-held air hammers for 6.5 to 7 hours per day or had done so within 2 years were symptomatic, having white fingers, numbness, tingling, swollen hands, loss of grip, and painful shoulders and elbows. The remaining workers using air hammers were not affected. Of the 1,904 workers who did not use air hammers, 16 were symptomatic and the remaining 1,888 were not. The study showed that the risk of developing these symptoms was greatest among users of air hammers and less among other workers using other tools, including grinders.

In the same report [94], a study of recently hired chippers and grinders showed that during 76 months of follow-up, 33 of 144 chippers (22.9%) and 7 of 34 grinders (20.6%) became symptomatic. Two chippers had symptoms after 4 months of work, but the first symptomatic grinders did not show up until after 9 months. The author concluded that this demonstrates that a longer latent period exists for grinders, even though the percentage who were symptomatic after 16 months of exposure was the same. The implication was that all chippers used air hammers and that was the cause for the earlier occurrence of Raynaud's phenomenon. However, several other factors that may be related to the occurrence of Raynaud's phenomenon are: (1) physical condition and maintenance of the pneumatic tool; (2) length of chisel used on the chipping tool; and, (3) force used in holding the tool. The recent studies by NIOSH support these findings [173].

D. Injuries to Foundry Workers

While the health hazards (chemicals, dusts, gases, and fumes) to which foundry workers are exposed are of great concern, equally important problems confronting foundry workers are the daily exposure to safety hazards that may result in injury or death. Incidents such as the explosion that killed 4 and hospitalized 17 workers at Burnside Steel Foundry in February 1979 [174] continue to occur because of poor work conditions and practices, inadequate engineering controls, and improper or inadequate training. The OSHA National Emphasis Program (NEP) consultation service program, conducted in 1977-78 [39], estimated that each worker in a foundry is at risk to approximately one and one-half serious "safety hazards" and two other-than-serious "safety hazards." A "serious hazard" is defined as one that could result in severe injury or death. The incidence rate for lost workday injuries was 14.9 cases per 100 full-time iron and steel foundry workers, which averages about three times that of all manufacturing industries [48].

1. Potential Sources of Safety Hazards in Foundries

Foundry worker accidents can result in injuries from (1) manual materials handling, (2) machinery, (3) walking and working surfaces, (4) mechanical materials handling, (5) foreign particles in the eye, and (6) contact with hot material. Injuries in all of these operations have resulted in disability, dismemberment, or death to foundry workers.

a. Manual Materials Handling

Manual materials handling in foundries involves the moving by hand of castings, cores, molds, molten metal in ladles or other devices, or any other material. The amount of manual materials handling in a foundry is highly dependent on foundry size, age, and layout [7]. In general, the smaller, older, nonferrous foundries have heavy manual materials handling requirements [175]. Overexertion and poor lifting techniques are the most prevalent causes of injury to foundry workers, especially in coremaking, cleaning, and molding operations [48,50,176]. In addition, workers handling castings or process tools often receive traumatic injuries by being struck by or who come in contact with these objects. Burns are often received by workers while handling hot cores in coremaking processes or from molten metal during pouring, melting, and inoculation operations because of inadequate personal protective equipment and work practices [48].

b. Machinery

In the 282 foundries visited during the OSHA NEP consultation service program [39], an average of four instances was found involving improper machine guarding that could potentially cause worker injury. Molding and coremaking operations, utilizing automatic and semiautomatic machinery, presented hazards from moving machine parts and flying or ejected materials [48]. Improper maintenance, repair, guarding, and use of grinders and abrasive wheels may also result in worker injury.

c. Walking and Working Surfaces

Injuries resulting from falls from elevated work surfaces may result in more severe injuries than most other foundry accidents. These occur in charging areas of cupolas and during maintenance and repair of mixers, mullers, and furnaces. Poor housekeeping and poorly lighted areas may result in slips, trips, and other types of falls on walking and working surfaces [48].

d. Mechanical Materials Handling

Foundry operations require significant movement of both heavy and molten materials. As a necessity and labor-saving convenience, a variety of mechanical handling devices such as cranes, hoists, monorails, conveyors, forklifts, trucks, and electromagnets are used. Stress on crane components is greater under the elevated temperatures found in a foundry operation than under normal temperatures. In addition, some of these devices are continuously vibrating, resulting in mechanical stress on nuts, bolts, chains, and cables which eventually may result in equipment failure. Such equipment failures may lead to major explosions, fires, spills, and burns [48].

e. Foreign Particles in the Eye

Because of the heavy use of abrasive actions for cleaning foundry castings, eye injuries occur frequently. Metal dust or chips may be propelled at workers during chipping, grinding, abrasive blasting operations, and abrasive wheel use. Ambient dust may also contribute to eye injury, unless adequate safety glass protection is provided [48].

f. Contact with Hot Material

The data pertaining to injuries from contact with hot materials are presented in Section III.D.2.c.

2. Statistical Data and Case Reports of Foundry Injuries

The 1973-80 Bureau of Labor Statistics (BLS) data show that the overall illness and injury rate (lost workday and nonworkday lost cases) in the ferrous foundries was two times that of manufacturing industries as a whole and about three times that of the private sector (Tables III-10 and III-11) [52,177,178,179,180]. These data include both occupational illnesses and injuries; however, occupational injuries account for more than 98% of the total cases [179]. Although, during the past 8 years, there has been some yearly variation in total cases and in incidence rates, there is no consistent trend that would indicate that conditions have become either better or worse.

Other recent studies have analyzed safety conditions in the foundry industry: the OSHA NEP study [181] conducted from 1975-77; the California Department of Industrial Relations, Division of Labor Statistics and Research (California) study of 1974-76 [48]; the AFS-Sponsored American National Standards Institute (ANSI) Safety Committee study [51]; and the 1981 Accidents Statistics (for foundries in Ohio), Industrial Commission of Ohio study [50].

The OSHA Hazard Analysis and Program Evaluation Study (HAPES) [181] was based on information collected by OSHA compliance officers during inspections of 86 foundries in 17 states for the NEP between March and June 1977. Of the 4,194 OSHA recordable case reports received, covering 20 million hours of exposure, 1,638 involved lost workdays, 5 were fatalities, and the remainder were nonfatal cases without lost workdays.

TABLE III-10. Comparative occupational injury and illness rates, 1973-76

Industry	SIC codes	1976 Annual average employment*	Incidence rates per 100 full-time workers															
			Total cases				Lost workday cases				Nonfatal cases without lost workdays				Lost workdays			
			73	74	75	76	73	74	75	76	73	74	75	76	73	74	75	76
Iron and steel foundries	332	225.1	32.0	30.4	28.5	26.9	10.3	11.6	11.4	10.7	21.7	18.8	17.1	16.1	156.7	163.1	191.4	173.0
Nonferrous foundries	336	82.3	29.0	27.6	22.1	22.8	9.9	11.1	8.1	9.6	19.0	16.5	14.0	13.2	134.9	151.8	141.6	148.8
All manufacturing	--	18,883.1	15.3	14.6	13.0	13.2	4.5	4.7	4.5	4.8	10.8	9.9	8.5	8.3	68.2	72.7	75.4	79.5
Total private sector	--	64,689.8	11.0	10.4	9.1	9.2	3.4	3.5	3.3	3.5	7.5	6.6	5.8	5.7	53.3	54.6	56.1	60.5

*In thousands

Adapted from references [52,177,178]

TABLE III-11. Comparative occupational injury and illness rates, 1977-80

Industry	SIC codes	1980 Annual average employment*	Incidence rates per 100 full-time workers															
			Total cases				Lost workday cases				Nonfatal cases without lost workdays				Lost workdays			
			80	79	78	77	80	79	78	77	80	79	78	77	80	79	78	77
Iron and steel foundries	332	209.6	23.6	26.0	24.6	24.4	13.0	11.4	11.6	10.9	12.2	13.0	13.0	13.5	183.0	186.0	169.2	164.0
Nonferrous foundries	336	90.7	21.3	23.5	23.0	22.6	12.0	10.9	11.2	10.4	10.4	11.5	11.8	12.2	162.5	177.9	158.7	166.2
All manufacturing	--	20,300.0	12.2	13.3	13.2	13.1	5.4	5.9	5.6	5.1	6.8	7.4	7.6	8.0	86.7	90.2	84.9	82.3
Total private sector	--	74,961.1	8.7	9.5	9.4	9.3	4.0	4.3	4.1	3.8	4.7	5.2	5.3	5.5	65.2	67.7	63.5	61.6

*In thousands

Adapted from references [179,180]

The California study [48] was based on 3,525 workers' compensation records of disabling injuries and illnesses from all foundries within the state during 1973-76. The disabling injuries and illnesses considered were those that resulted in worker absence for at least a full day or a workshift beyond the day when the accident occurred.

The AFS study [51] considered 2,844 OSHA-recordable cases which were submitted voluntarily by 26 sand-casting foundries at the request of the AFS/ANSI Safety Committee. The reports covered only the injuries and illnesses that occurred in 1972. The California and AFS studies each presented the total number of injuries in each job category considered, while the HAPES study presented the data as either lost workday cases or nonfatal cases without lost workdays. All lost workday cases were reviewed, but only a portion of the nonfatal cases without lost workdays were reviewed because of insufficient time. The incidence rates of and total injuries listed in all three studies are presented in Table III-12. Six categories of injury hazards are discussed: (1) strains or overexertion; (2) struck by or contact with objects; (3) contact with hot materials; (4) caught in or between machine parts or struck by ejected objects; (5) falls; and, (6) foreign substances in the eyes.

a. Overexertion

Injuries resulting from strains or overexertion were reported to be the most frequent type involving lost workdays in both the California study (30% of all injuries reported) [48] and the HAPES study (1981) [181]. Both studies showed that most of these injuries occurred in the molding and coremaking departments during manual materials handling such as the lifting and lowering of molds, jackets, and cores. Typical examples of overexertion included: a worker who lost 34 workdays when he strained his back pulling on a stuck box; another worker who sprained his back while lifting pieces of metal labelled "50 kg (110 lbs)" which he mistakenly read as "50 lbs (22.6 kg)"; and a worker who sprained his forearm while pouring molten aluminum from a ladle [176].

b. Struck by or in Contact with Objects

Injuries resulting from being struck by or coming in contact with objects were found to be the second most frequent type involving lost workdays in the California study (15.8%) [48], the second most frequent in the AFS study (17.6%) [51], and the most frequent type in the HAPES study [181]. These injuries occurred most frequently in the cleaning and finishing departments, usually during the handling of castings and hand tools, and in the melting, pouring, molding, and coremaking departments, during the handling of molds, flasks, cores, and hand tools. Workers in the melting and pouring areas commonly experienced injuries when handling scrap metals, castings, and hand tools [48].

TABLE III-12. Injury incidence from the California, HAPES, and AFS studies

Cause of injury by category	California study		HAPES study		AFS study	
	No. of disabling injuries	Percentage	No. of total cases	Percentage	No. of OSHA recordable cases	Percentage
Strains or overexertion	**1,071**	**30.4**	**517**	**19.2**	**247**	**15.8**
Lifting castings, cores, metal scrap	623		117		223	
Pushing or pulling molds, cores, wheelbarrows	81		64		17	
Handling molds, castings, ladles	131		106		N/A	
Using tools or shovels, sledgehammers, molding machines	122		39		N/A	
Other	114		151		N/A	
Chronic	N/A		40		7	
Struck by or in contact with	**558**	**15.8**	**558**	**20.7**	**276**	**17.6**
Dropped while handling castings, molds, scrap metal, containers	148		205		45	
Otherwise handling	209		156		N/A	
Handtools	N/A		75		2	
Rubbed or abraded	N/A		75		229	
Other	201		47		N/A	
Contact with hot materials	**356**	**10.1**	**241**	**8.9**	**23**	**1.5**
Hot or molten metal	245		111		N/A	
Hot objects: molds, castings	37		68		N/A	
Other	74		62		23	

N/A - Not available or applicable due to variations in initial compilation categories of separate studies.

Adapted from references [48,51,181]

TABLE III-12. Injury incidence from the California, HAPES, and AFS studies--Continued

Cause of injury by category	California study		HAPES study		AFS study	
	No. of disabling injuries	Percentage	No. of total cases	Percentage	No. of OSHA recordable cases	Percentage
Caught in or between machine parts or struck by ejected objects	225	6.4	251	9.3	62	4.0
Point of operation	N/A		109		11	
Moving machine parts	N/A		79		51	
Struck by object ejected	N/A		63		N/A	
Falls	267	7.6	338	12.5	85	5.4
Hazardous floor conditions	90		151		54	
From elevation	35		116		31	
Other	142		71		N/A	
Foreign substances in eyes	383	10.9	354	13.1	707	45.3
Metal scrap, chip, or dust	205		187		N/A	
Molten metal, slag	30		9		N/A	
Sand	6		33		N/A	
Other	142		125		707	
Total, categories presented	2,860	81.1	2,259	83.9	1,400	90
Total, including other miscellaneous categories	3,525	100	2,694	100	1,561	100

N/A - Not available or applicable due to variations in initial compilation categories of separate studies.

Adapted from references [48,51,181]

c. Contact with Hot Materials

Burns accounted for approximately 10% of the lost workdays in both the California (10.1%) [48] and HAPES (9.6%) [181] studies. Melting and pouring operations accounted for the majority of the burn injuries. Burns resulted from worker contact with molten metal; the majority were foot burns. The HAPES study [181] observed that in nearly all of the cases in which workers' feet were burned, the injuries might have been reduced in severity or prevented if proper protective footwear, e.g., nonflammable metatarsal guards, had been worn. Spats and gaiter-type boots worn inside the trousers are necessary because serious burns in foundries do occur when molten metal is spilled on the legs or inside the shoes [176].

d. Caught in or Between Machine Parts or Struck by Ejected Objects

Foundry machinery, such as automated or semiautomated molding and coremaking, presents a serious hazard from exposure to both flying or ejected materials and moving parts. The grinding operations in the cleaning and finishing departments account for numerous injuries from flying particles.

The HAPES study [181] listed contact with machine gears, pulleys, belts, and operating machine points as the causes of more than 8% of foundry lost workday injuries. The California study [48] reported that 6.4% of the lost workday cases involved workers being caught in or between moving machine parts.

e. Falls

In the HAPES study, injuries resulting from falls on or from walkways or work surfaces were the second most frequent cause of lost workday cases (13.8%) and ranked second in actual days lost (18.0%). Such falls also accounted for two of the five fatalities reported in the HAPES study [181]. The California study reported 7.6% of the lost workday cases involved falls [48].

Injuries due to falls from elevated work surfaces, ladders, stairs, or platforms are commonly more severe than those due to falls occurring on the same level. The majority of injuries involving slipping on substances or tripping over objects resulted from poor housekeeping practices where floors were wet, slippery, or littered.

f. Foreign Substances in the Eyes

Eye injuries were the most frequent nonfatal injury involving no lost workdays and the third most frequent cause of lost workdays reported in the HAPES study [181]. The California study recorded eye injuries as almost 10% of the lost workday cases [48]. In the AFS study, eye injuries occurred in 45.3% of all the reported injuries [51].

By far, the most frequent form of eye injury is caused by a foreign substance in the eye, either from dust in the air or particles propelled in foundry operations. These flying objects include metal chips; dust and abrasive material from cleaning, finishing, and grinding operations; sand in coremaking and molding operations; and metal particles, molten metal, and molten metal/steam explosions in melting and pouring operations. For the most part, the hazard of flying particles can be effectively reduced by a combination of machine safeguarding, personal protective equipment, and safe work practices.

The founding process generates a considerable amount of particulate matter in almost all operations. Engineering controls can significantly reduce worker exposure to dust hazards but cannot control eye injuries from propelled particles and eliminate dust hazards completely. In cleaning and finishing operations, even the use of air-supplied helmets has not completely prevented foreign substances from entering the eyes.

IV. ENGINEERING CONTROLS

The foundry environment may be a potential source of numerous toxic air contaminants such as silica, CO, and thermal decomposition products; physical hazards such as noise, heat, and vibration; and safety hazards, including contact with molten metal. The short- and long-term health and safety effects of the potential hazards, in general, and illustrated how they may affect foundry workers are reviewed in Chapter III. In order to reduce worker exposure, foundry hazards must be adequately identified and evaluated, and engineering controls, administrative controls, work practices, and, when appropriate, personal protective clothing and equipment should be applied [7,59,182]. Ventilation, enclosures, barriers, and substitution of less toxic materials and hazardous processes can be utilized to help control safety and health hazards in different foundry operations [7].

To improve working conditions in foundries, proper consideration should be given to controlling dust and fumes, especially silica dust, by engineering methods. A plant that is well-designed from environmental and production standpoints will have a substantially reduced need for dust control. However, when a plant design is not adequate to eliminate the dust and fume hazards, retrofit control procedures must be introduced.

A. Preparation of Mold Materials

The preparation of mold materials involves recovering sand and other materials from the shakeout and adding new binder materials and sand for mold production. The addition and recovery of sand and binders are major contributors to the crystalline silica and other dust hazards in the foundry air [183]. In addition to crystalline silica, other hazards may result during mold material preparation. For example, hot green sand may produce steam when passing through the sand preparation system, or smoke may result from high sand temperatures and the presence of organic corebinding materials [15,184].

Data from NIOSH Health Hazard Evaluations (HHE's) confirm that crystalline silica is a health hazard in sand preparation areas of ferrous and nonferrous foundries [35,36,37,38]. In a 1974 NIOSH HHE of a semiautomated foundry, concentrations of respirable free crystalline silica dust in 14 of 17 personal samples taken exceeded the NIOSH recommended 10-hour TWA of 50 $\mu g/m^3$. The major sources of atmospheric contamination in the sand preparation area were leakage of dust from containing bins, inadequate containment of hot sand at shakeout operations, inadequate exhaust ventilation, and sand spillage at transfer points [36].

In a brass foundry surveyed by NIOSH in 1975 [37], potentially toxic respirable crystalline silica dust concentrations were found in all the sampled areas. Utility workers assigned to sand pile and sand spillage cleanup, in areas where ventilation was minimal, were exposed to silica concentrations of 0.07 to 1.05 mg/m^3 during a 6-7 hour sampling time. Improving control of conveyor and muller leakage and enclosing and mechanizing the transfer of materials from the conveyor pit would reduce the environmental crystalline silica concentrations [37].

In a steel foundry surveyed by NIOSH [35], the molding sand (72% crystalline silica) was prepared in a muller loaded by a mechanical bucket lift but filled manually. After mixing, the sand was delivered to each work location by wheelbarrow. Used sand was recycled by processing the shakeout wastes through a riddle, which removed slag and solid wastes, and then the reusable sand was shot 10-20 feet (3-6 meters) through the air into a storage bin. Personal respirable crystalline silica exposure concentrations for mullers and laborers during an 8-hour workshift in the sand preparation area ranged from 0.10 to 0.82 mg/m^3, exceeding the NIOSH recommended TWA of 50 μg/m^3 [35].

In sand reclamation systems, the sand is usually dry from the knockout or shakeout process to the point at which binders and other materials are added [185]. To eliminate dust in the green-sand systems, this dry part of the cycle must be controlled as much as possible.

The basic foundry principle, that the temperature of a foundry sand system varies with the sand-to-metal ratio of the molding operation, was applied in developing the Schumacher process [186]. At normal molding ratios of 3 to 7 sand: 1 metal, the sand forming the mold becomes hot when the molten metal is poured into the mold cavity; therefore, a higher sand-to-metal ratio will result in a cooler sand temperature resulting in less dust. Management generally prefers a low sand-to-metal ratio because it permits more castings per mold; but the hot dry sand produces more dust during shakeout and subsequent sand-handling operations than do the low sand-metal ratios.

The Schumacher system may solve the problems of hot sand and resultant high dust exposure while still allowing high metal loading without sacrificing a low sand ratio in the sand system [7,186]. Moist sand from the mixer is diverted into two streams: about one-fourth of the total amount is transported to molding operations and the remaining three-fourths bypasses the molding operation and rejoins the used molding sand at the casting shakeout. The mass of cool, moist sand that bypasses the molding and pouring operations cools the molding sand. Thus, a foundry can pour a high number of castings in each mold with little regard for the heat build-up in the low sand-to-metal ratio molds [186]. The mixture of used sand and cool-damp sand, which was added at the shakeout, quenches dust and heat. Foundry sand that contains more than about 2% moisture evenly distributed is unlikely to be a significant source of dust [187].

The usual sand cooling methods, such as spraying with water or forcing large amounts of air through the sand, create steam or dust clouds which must be controlled by collectors under many local air pollution codes. The Schumacher process can decrease the need for dust-collecting devices used in conventional systems [7,186]. Another approach to controlling silica dust is the use of chemically-bonded sands. This requires less sand (approximately 3,000 pounds vs. 7,000 pounds for 1,000 pounds of castings) thus reducing the potential for sand spillage and dust dispersal.

Returned sand contains an increased amount of silica "fines," which may become entrained in the air as hazardous crystalline silica dust if the work area is not adequately ventilated [187,188]. This increased dust is due to the presence of bonding and other conditioning materials, as well as to the drying and the mechanical and thermal breakdown of the sand. Although fines are necessary for adequate permeability in sand molds, most can be removed by dry or wet reclamation systems. Conveyors, elevators, bins, and transfer points should be enclosed and ventilated to control the air concentration of free silica fines in areas where the sand contains less than 2% of moisture by weight [7,184,188,189]. Conveyor enclosures will also reduce the potential for sand spillage.

The condensation of water and oil vapors in the ducts with entrapment of dust, which can plug the duct when water- and oil-sand mixes are used, can seriously compromise an otherwise adequate exhaust system. Frequent inspection and duct cleaning are required.

An important ventilation point is under the knockout or shakeout grid [184], where the sand usually falls into a hopper with a conveyor at its base. If the sand is hot and moist, steam may have to be controlled by covering and exhausting the conveyor for some distance from the knockout grid. If the sand is hot and dry, the conveyor may also have to be covered and exhausted for a sufficient distance to control heat and dust. If local exhaust ventilation is needed, it should be applied to the cover of the conveyor at suitable points from 25 to 30 feet (7.6 to 9.1 meters) apart [184]. Figures IV-3, IV-4, and IV-5 show examples of ventilation for controlling exposures along conveyors and transfer points.

Adequate belt conveyor designs can reduce sand spillage in mechanized foundries [187]. Conveyor belts should be designed for peak loading, estimated as double the maximum sand flow needed for molding, even if this is only needed for short periods. To reduce sand spillage, belts should be run at speeds <1.25 m/s to allow for satisfactory operation of ploughs and magnetic separators. Trough angle, another design consideration, was previously limited to 20 degrees. With new nylon belts that permit angles up to 45 degrees, the belt capacity should be half that of the equivalent width of a 20 degree troughed belt, or spillage will occur. Belt inclination also affects the amount of slipping and rollback that takes place. The maximum belt inclination should be 17 degrees for knockout sand carried by 20 degrees troughed belts and 18 degrees for prepared molding sand. Special belts with molded crossbars may be used at inclinations up to 50 degrees. When sand sticks to the belt, belt cleaners which are enclosed and exhaust-ventilated should be used, e.g., a static scraper or a rotary cleaner. In addition, the type of belt-fastening used affects sand leakage. Only a vulcanized joint is leak-proof; it should be used instead of mechanical belt fasteners [187].

With pneumatic conveying, as an alternative to an elaborate conveyor belt system, the sand is moved by differential air pressure through pipes, which provide complete enclosures for the material being conveyed. Apart from being almost dust-free, pneumatic conveying permits complex plant layouts and takes up little space. Some of the advantages of the pneumatic conveyor system are cleanliness and the flexibility it provides for plant layout. Disadvantages are power consumption, maintenance costs, and initial capital cost [187].

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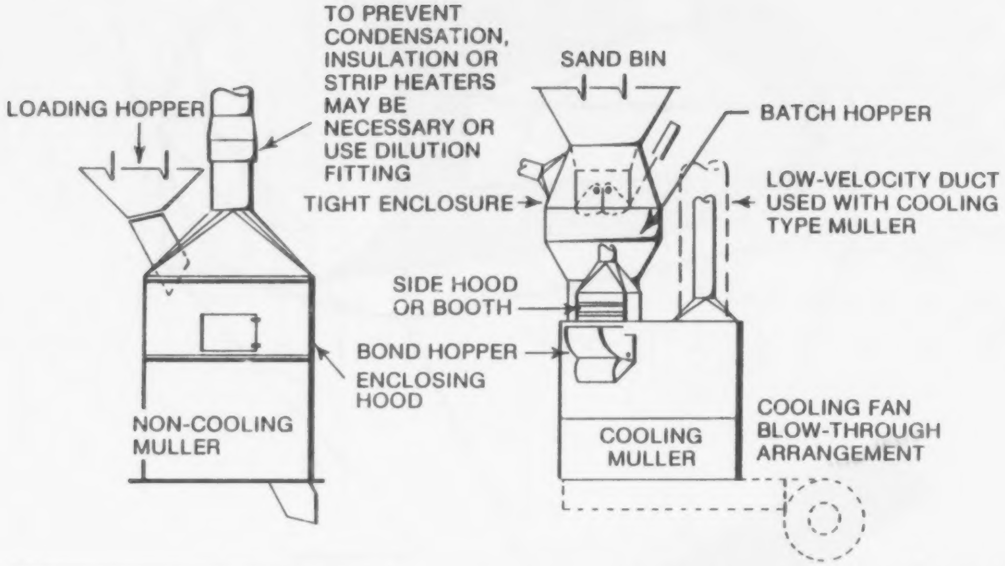
Returned and new sand are conditioned by screening, cooling, blending, and adding bonding ingredients and moisture. Local exhaust ventilation is usually necessary at all screens, transfer points, bins, sand mullers and conditioning machinery because of the dusty conditions created during sand handling [184,188,190]. In ventilating vibrating flat deck screens and rotary screens, exhaust air velocities entering the duct connection must be as low as possible to minimize the loss of usable sand fines (Figure IV-6). At the same time, air velocity in the duct must be high enough to prevent the coarse fraction of dust from settling out in order to minimize plugging [188]. Recommendations for controlling dust from mixer and mulling operations are shown in Figures IV-7 and IV-8.

Where sand and other mold materials are handled, local exhaust ventilation should be applied. However, applying local exhaust ventilation is difficult in certain manual operations, e.g., shoveling and sweeping operations [191]. In some cases, moisture can be added to satisfactorily reduce the dust hazard, but the added moisture may increase the level of heat stress by increasing the humidity. Because local exhaust ventilation cannot always be applied in sufficient amounts in pits below conveyor lines, workers who clean these areas may have to wear respirators [192]. Handling bagged additions of clay and coke can be a dusty and dirty operation, and local exhaust ventilation should be provided [184].

Dust, vapors, and gases may be produced in and around mullers and other sand-handling equipment during the preparation of materials for molding [76]. In foundries that use shell molding, the dust concentrations, particle size, and crystalline silica content of the airborne dust can create the same risks to workers as those present in conventional foundry operations. In addition, combustible concentrations of resin may be present at sand-conditioning areas in which the dry blending method is used, producing a dust explosion hazard. Solvents such as methyl and ethyl alcohol, which are used to dissolve the resins sufficiently to produce a suitable uniform particle coating, can produce vapor concentrations that approach the lower explosive limit (LEL). To decrease potential exposure to crystalline silica and solvents, local ventilation should be used at the mixer, with increased exhaust volumes for solvent vapor control [76]. When resins and sand are mixed in the foundry, control should be provided by exhausting sufficient air through the system to ensure the maintenance of explosive vapor concentrations at or below 25% of the LEL for the vapor [188,193]. Local exhaust ventilation may also be necessary at the opening of chutes through which the resin is added and the mixture discharged [184]. Because of ventilation requirements and sand availability, more foundries are converting to precoated sand for shell and no-bake operations [175].

B. Molding Operations

The molding process involves several distinct operations, including blowing old sand off the pattern, discharging a measured amount of tempered sand into the flask, jolting or vibrating the flask to settle and pack the sand, and squeezing the pattern into the sand [3,5]. Each of these operations, although performed by a variety of methods, may produce high levels of noise [7,115,194] and dust [7,38,57,115,195].

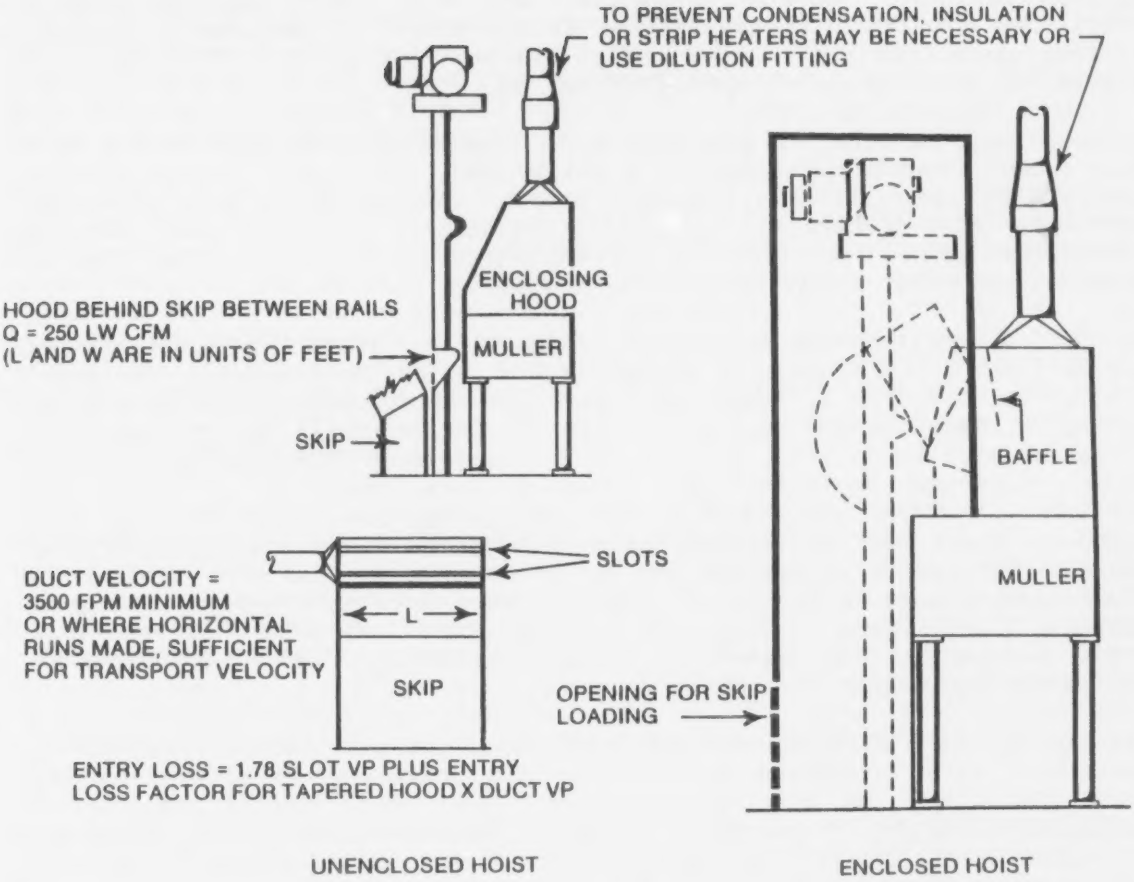

TO PREVENT CONDENSATION, INSULATION OR STRIP HEATERS MAY BE NECESSARY OR USE DILUTION FITTING
SAND BIN
LOADING HOPPER
BATCH HOPPER
LOW-VELOCITY DUCT USED WITH COOLING TYPE MULLER
TIGHT ENCLOSURE
SIDE HOOD OR BOOTH
BOND HOPPER
ENCLOSING HOOD
NON-COOLING MULLER
COOLING MULLER
COOLING FAN BLOW-THROUGH ARRANGEMENT

MIN. EXHAUST VOLUME FOR NON-COOLING MULLERS	
MIX. DIAMETER (FEET)	MIN. EXHAUST (CFM)
4	750
6	900
7	1050
8	1200
10	1575

- Q = 150 CFM/SQ FT THROUGH ALL OPENINGS, BUT NOT LESS THAN THE TABLE VALUES FOR NON-COOLING MULLERS
- DUCT VELOCITY FOR NON-COOLING MULLER = 3500 FPM MINIMUM
- DUCT VELOCITY FOR COOLING MULLER = 4500 FPM MINIMUM
- ENTRY LOSS FOR TAPERED HOOD = ENTRY LOSS FACTOR FOR TAPERED HOOD X DUCT VP
- ENTRY LOSS FOR SLOTTED SIDE DRAFT HOOD = 1.78 SLOT VP PLUS ENTRY LOSS FACTOR FOR TAPERED HOOD X DUCT VP
- ENTRY LOSS FOR ROUND DUCT WITH FLANGE = 0.49 DUCT VP

FIGURE IV-7. Mixer and muller ventilation

Adapted from reference [190]


TO PREVENT CONDENSATION, INSULATION OR STRIP HEATERS MAY BE NECESSARY OR USE DILUTION FITTING
ENCLOSING HOOD
HOOD BEHIND SKIP BETWEEN RAILS
Q = 250 LW CFM
(L AND W ARE IN UNITS OF FEET)
MULLER
SKIP
BAFFLE
SLOTS
DUCT VELOCITY = 3500 FPM MINIMUM OR WHERE HORIZONTAL RUNS MADE, SUFFICIENT FOR TRANSPORT VELOCITY
L
SKIP
MULLER
OPENING FOR SKIP LOADING
ENTRY LOSS = 1.78 SLOT VP PLUS ENTRY LOSS FACTOR FOR TAPERED HOOD X DUCT VP

UNENCLOSED HOIST

ENCLOSED HOIST

FIGURE IV-8. Skip hoist ventilation for mixers and mullers

Adapted from reference [190]

In the past, the primary source of silica exposure of molders was from the use of silica parting powders [115,195,196]. Renes et al. [115], in 1948-49, performed time-motion studies of machine molding operators in ferrous foundries and found that more than an hour of the molders' time over a 9-hour workshift was spent applying parting compounds to molds and patterns. The average dust exposure during that time was 2.5 million particles per cubic foot (mppcf), contributing 70% of the molders' total exposure. Because of the health hazards of silica dust exposure and with the development of liquid parting fluids and suitable replacements such as calcium carbonate, calcium phosphate, and talc [197], parting powders containing more than 5% crystalline silica should be avoided in foundry molding operations [196]. The use of silica flour as a parting agent is prohibited in the United Kingdom [184,185,198].

Although mold material is generally moist, levels of respirable silica have been shown to exceed the NIOSH REL's [35,38,199]. In a 1977 ferrous foundry survey [38], crystalline silica environmental concentrations over an 8-hour workshift for workers at pin-lift, squeezer, and roll-over molding operations ranged from 0.05 to 0.97 mg/m^3; 12 of the 13 personal samples exceeded the NIOSH REL of 50 μg/m^3 (0.05 mg/m^3).

In 1976, a comprehensive survey was conducted in Finland [195] determining crystalline silica exposure among molders using mold process equipment similar to that of U.S. foundries. Dust and silica measurements were taken during various foundry operations for an entire shift on at least two different days in 51 iron, 9 steel, and 8 nonferrous foundries; a total of 4,316 foundrymen were employed. Samples were taken on at least two different days for an entire shift during various operations in each foundry. About half of the samples were collected in the workers' breathing zones. The sample collection and analysis methods used were similar to NIOSH methods used in the United States. Mean respirable silica (<5 micron particle size) concentrations for molding operations were 0.31 mg/m^3 in iron foundries, 0.27 mg/m^3 in steel foundries, and 0.22 mg/m^3 in nonferrous foundries.

The crystalline silica content and total dust levels at the various foundry operations were influenced by the size and mechanization of the foundry facilities [57]. For molding operations, total environmental dust levels decreased slightly, from 10 to 7 mg/m^3, as the size of the foundries increased. This was attributed to the increased mechanization of molding operations in larger foundries.

To reduce the exposure of molders to crystalline silica and other dust hazards, sand moisture content must be retained, sand binders or sand substitutes can be used, or adequate ventilation and spill protection must be provided. High levels of dust may be generated from dry sand during flask filling when sand is discharged from a hopper immediately overhead and in front of the operator and falls freely past the worker's breathing zone, and when sand builds up due to spillage around mold machines and during portable vibration and agitation in manual core and mold ramming [7,115]. Silica sands can be kept moist by proper cooling and rewetting before and during mulling and by restricted storage time of prepared sand [7]. Pits under mold machines should be provided to catch spills, and sand should be removed before it is allowed to dry [7]. This can be achieved by having a conveyor system beneath the pits to remove sand from the area and return it to the muller.

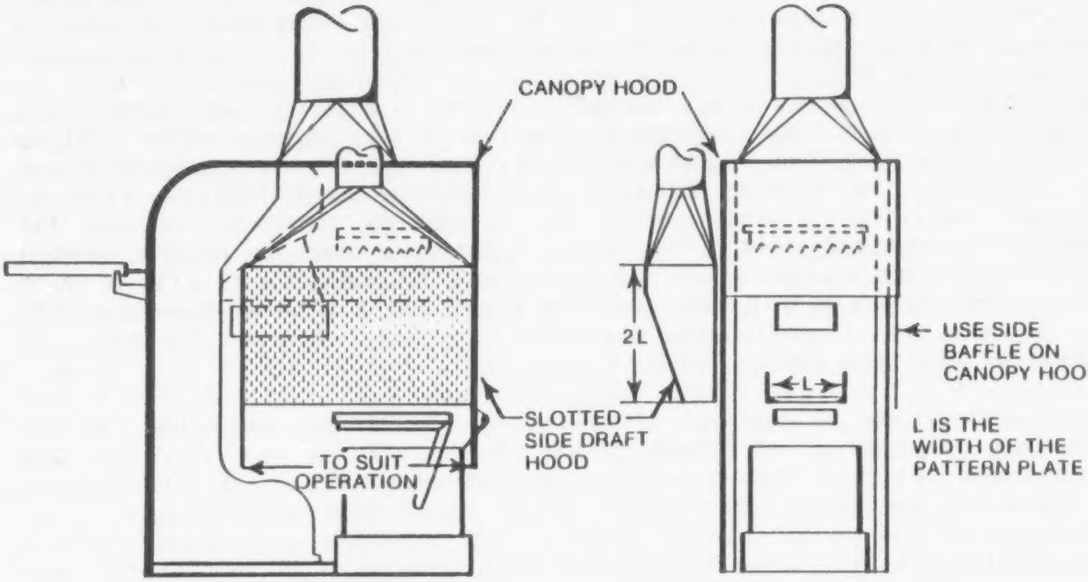
Dust exposure near sand slingers is usually excessive because of the high velocity release of finely divided dry sand particles near the slinger head [7]. Enclosing the slinger operation or isolating the slinger operator in a remote control station are effective ways to reduce the dust contamination of the breathing-zone air of the operator. Exhaust ventilation in the spill pit below the slinger will cause a low-velocity downdraft around the flask which, although insufficient to capture the dust at its source, will cause a constant turnover of air around the flask and help reduce dust in the area. Such ventilation is important not only to the slinger operator but also to other line workers who are close to the slinger.

Substitution of non-silica (e.g. olivine) molding aggregate can substantially reduce the airborne crystalline silica concentration. Field tests have been conducted to compare the air quality in a foundry before and after changing the molding material from silica-based sand to olivine. Processes involving no-bake molding and coremaking continues to use the standard silica-based sand. The data indicates a decline in the average crystalline silica content after the changeover by a factor of 2 to 5 (from 12.7 to 2.6% by weight in the shakeout area, and 8.2 to 4.9% on the main floor). More significantly, the deviation of the values from the mean was reduced, as was the range [17].

In a 5-year study of the use of olivine in nonferrous foundries, it was found that the pattern of contamination of the olivine sand by clays and silica cores was such that a constant concentration of silica sand dust in the system was reached in about a year after the olivine mold sand was first installed in the sand system [18]. The airborne crystalline silica concentrations also increased during this period, following the same pattern. However, the level of airborne dust and crystalline silica in the foundries using olivine was lower than that in other foundries; the percent by weight of crystalline silica was 80% less than in foundries using silica sand.

At present, there does not appear to be a practical method for separating the silica core material from the olivine mold sand during recycling. If the olivine is not recycled, it becomes too expensive for routine use. The substitution of non-silica materials for silica cores is becoming more widespread and would appear to be a good method for reducing worker exposures to crystalline silica. However, more research is needed to determine the toxicity of silica sand substitutes and the cost of the changeover.

Shell molding machines pose special exposure problems because dust, heat, vapors, and gases are released, especially following removal of the mold from the molding machine [76,188]. Figure IV-9 illustrates a recommended method for ventilation control of shell molding equipment (also see reference [76]).


CANOPY HOOD
2L
USE SIDE BAFFLE ON CANOPY HOOD
L
SLOTTED SIDE DRAFT HOOD
TO SUIT OPERATION
L IS THE WIDTH OF THE PATTERN PLATE

FOR SLOTTED SIDE DRAFT HOOD:
Q = 75 (10 x^2 + HOOD AREA) CFM
ENTRY LOSS = 1.78 SLOT VP PLUS ENTRY LOSS FACTOR FOR TAPERED HOOD X DUCT VP

FOR CANOPY UNITS:
Q = 250 CFM/SQ FT OF THE FACE OF THE CANOPY FOR SINGLE UNITS
= 150 CFM/SQ FT OF THE FACE OF THE CANOPY FOR DOUBLE UNITS
ENTRY LOSS = ENTRY LOSS FACTOR FOR TAPERED HOOD X DUCT VP

FIGURE IV-9. Shell coremolding equipment

Adapted from reference [190]

The noise created by molding machinery is complex due to the wide variety of noise sources within the area. Excessive noise is caused by the action of the machines, such as when jolt molding machines produce noise from the rapid impact of the jolt piston against the table, as well as by ancillary processes, such as compressed air blowoff to clean the pattern for the next molding run [194].

In a NIOSH control technology study [7], the complexity of the noise problem was described and some control solutions recommended for large iron and steel foundries. The molding area in the foundry studied was composed of 18 jolt-squeeze machines located in a line. The overall noise level generated during the molding operation ranged from 75 to 125 dBA (the OSHA PEL is 90 dBA for an 8-hour TWA). The major noise sources were the jolt and squeeze operations, pattern vibrators, the air nozzle during cleaning, air circulation fans, and the vibration of the hopper during flask filling.

Various types of elastomer pads were used to try and reduce the high jolting impact noise. Initially, the pads reduced peak noise, but they wore out very quickly. In addition, mold quality suffered because the jolting force was reduced by the cushioning action of the elastomer pads. To reduce the noise from squeeze operations, the molding machines were retrofitted with a quiet, rapper-type mechanism used to compress the pattern into the molding sand; it performed well and substantially quieted this part of the operation.

Piston-type vibrators were found to generate the greatest force to compact the mold and the loudest noises. Turbine and rotary vibrators generated much less noise yet produced sufficient force to separate the sand from the pattern or shake it loose from the hopper. In addition, lining the sand hoppers with a plastic material allowed the sand to flow more freely, requiring less vibration.

A nozzle with a flow-through design decreased noise from the air nozzle used to blow excess sand off the flasks and patterns. This substitution resulted in a 10-dBA decrease in the overall sound levels. Installation of exhaust mufflers on the high pressure discharge air of the molding machines decreased the noise levels.

With these equipment changes, the ambient noise level in the area emanating from the shakeouts and other processes was greater than the level generated by the molding machine. The noise generated by a single molding machine with exhaust mufflers was about 85 dBA for an 8-hour TWA. Before the noise reduction, the operator was exposed to a noise level of 85 to 106 dBA. The overall reduction was about 8 dBA over an 8-hour period [7].

C. Coremaking Operations

Coremaking operations, depending on the type of coremaking system, can be a source of heat, dust, noise, and chemical emissions [7]. In sand-casting foundries, coremaking processes may expose workers to high levels of crystalline silica dust, sometimes exceeding the 10-hour TWA, NIOSH REL of 50 $\mu g/m^3$ (based on a 40-hour workweek) [38]. Respirable crystalline silica concentrations in 6-hour dust samples taken at two types of coremaking processes in a ferrous foundry (a no-bake core and a shell core operation) ranged from 0.12 to 0.33 mg/m^3 in the no-bake core and from <0.04 to 0.06 mg/m^3 in the shell core operation. All of the crystalline silica concentrations at the no-bake operation exceeded 0.05 mg/m^3, as did one of two samples collected at the shell core operation. The crystalline silica concentrations at the no-bake core process were attributed to its location immediately adjacent to sand molding and metal pouring stations; the shell core process was located in a separate room, removed from dust generated by processes such as sand molding and metal casting [38].

Silica in coremaking operations can be controlled by maintaining optimal sand moisture content [7], by providing adequate ventilation [7,190], and/or by using non-silica sands [200]. Figure IV-10 gives recommended ventilation controls for small rollover-type coremaking machines in areas where air contaminant concentrations exceed recommended exposure limits. Using non-silica aggregates for aggregate sand reduces adhering sand defects, thereby reducing silica exposures in the cleaning room and the coreroom [200].

1. Oven-Baked Cores

Oven-baked cores usually contain binding agents and other materials, e.g., oleoresinous binders (core oils), combinations of synthetic oils (fatty esters), petroleum polymers, and solvents or thinners, such as kerosene and mineral spirits [13,15,201]. During the baking of oil-bonded cores, smoke and fumes are produced from the thermal decomposition of the organic core materials and from the release of the solvents from the core [201,202].

To control the chemical emissions produced during oil-based, oven-baked coremaking, ventilation and good core-baking techniques are required [184,188]. Modern batch- and continuous-type core ovens are usually provided with internal ventilation to promote good air circulation and proper core drying [175,188]. However, if the ventilation is not adequate to capture the fumes released at the oven doors or other openings, small slot- or canopy-type hoods will be needed for effective fume control, even if the oven is in good condition and does not have serious leaks [188].

The sand used in oven-baked cores should be cool before mulling. Only the minimal necessary amounts of binder should be added to the formulation because excess oil for binding produces smoke, thermal decomposition products, and carbon monoxide gas when the cores are baked. In addition, oil-bonded cores should be properly baked because underbaked cores produce excess gas during casting [188,201].

2. Shell Coremaking

Shell cores are usually produced with phenol-formaldehyde resins, using hexamethylenetetramine as a catalyst. Phenol, hydrogen cyanide, carbon monoxide, formaldehyde, ammonia, and free silica are potential hazards in shell coremaking [13,22].

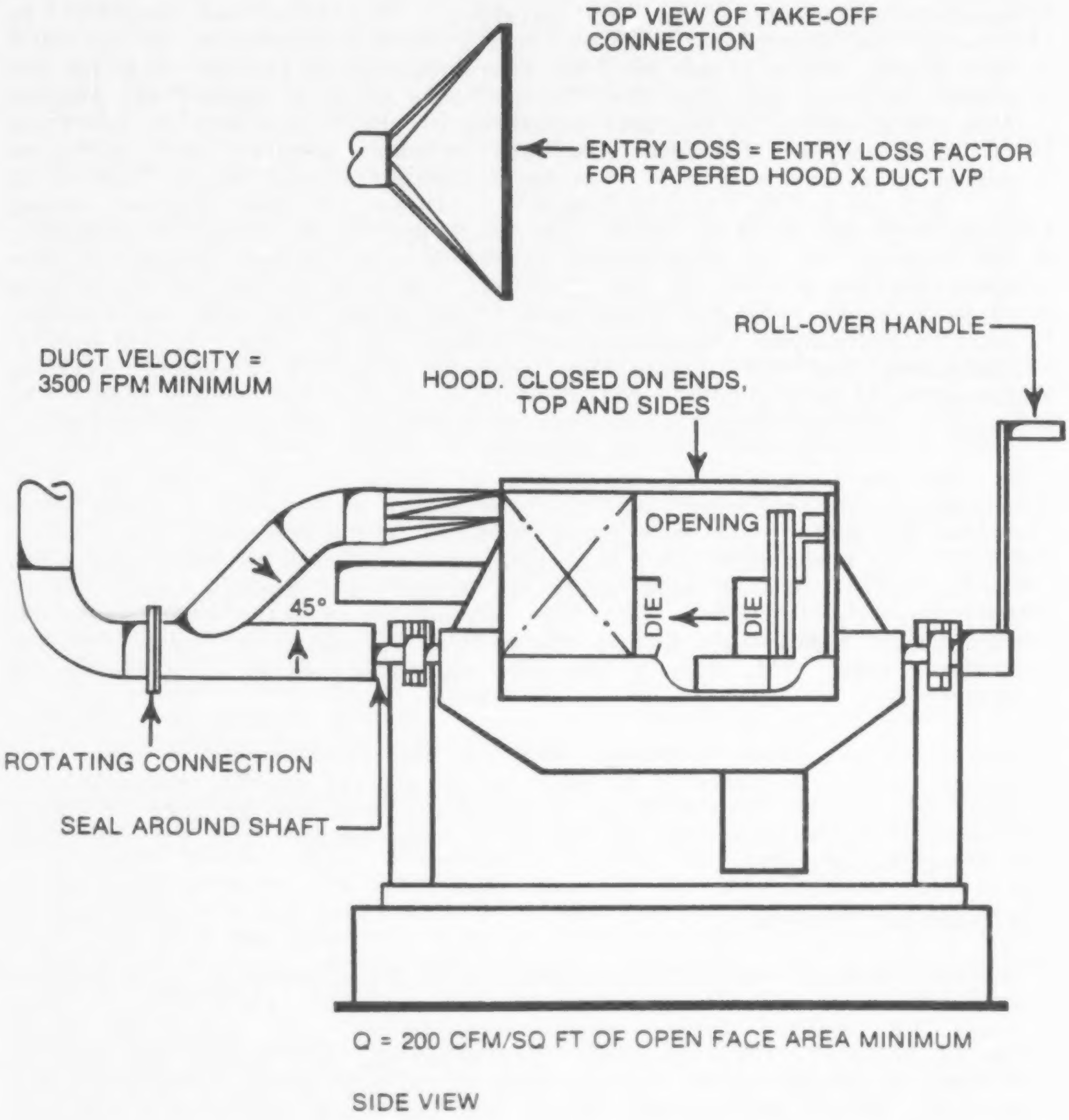

TOP VIEW OF TAKE-OFF CONNECTION
ENTRY LOSS = ENTRY LOSS FACTOR FOR TAPERED HOOD X DUCT VP
ROLL-OVER HANDLE
DUCT VELOCITY = 3500 FPM MINIMUM
HOOD. CLOSED ON ENDS, TOP AND SIDES
OPENING
45°
DIE
DIE
ROTATING CONNECTION
SEAL AROUND SHAFT
Q = 200 CFM/SQ FT OF OPEN FACE AREA MINIMUM
SIDE VIEW

FIGURE IV-10. Small rollover-type coremaking machine

Adapted from reference [190]

The exposure of shell core machine operators to hazardous substances was recently investigated in a ferrous foundry [38]. The shell cores were prepared from a urea-phenol-formaldehyde sand mixture with hexamethylenetetramine as the catalyst. The core was produced by blowing the sand-binder mixture into a corebox preheated to 400-450°F (204-232°C), where it was held for approximately 30 seconds to allow the binder to cure, and then the finished core or core segment was removed from the corebox. To evaluate exposures of shell core machine operators to formaldehyde, fourteen 30-minute personal samples were collected during an 8-hour workshift. Airborne concentrations ranged from <0.02 to 18.3 ppm (<0.02 to 22.5 mg/m^3). Three of the samples showed concentrations of 4.4, 10.6, and 18.3 ppm (5.4, 13.0, 22.5 mg/m^3). The fluctuations of formaldehyde levels were mainly attributable to core types and sizes. During one 30-minute sampling period in which nine large cores (size unspecified) were formed along with some small cores, the formaldehyde concentration was 10.6 ppm (13.0 mg/m^3). Recommendations for controlling operator exposure included removing contaminants during core cooling by using a spray booth-type hood or by using a blowing/extraction ventilation system at transport points [38].

In the shell coremaking operations of three British foundries, high concentrations (not specified) of formaldehyde were found in areas where hollow cylindric cores were being produced in the absence of ventilation [203]. The cores were 2.6 X 0.5 feet and were closed at both ends. The hollow center of the mold contained phenol and ammonia vapor, as do other shell molds, but in this case the hot cores were removed from the machine and broken open across the middle, releasing hot vapor into the worker's face. This type of exposure can be prevented by allowing the sand to cool before breaking the core tree.

Control of exposures to phenol, ammonia, and formaldehyde in shell core production can be achieved by ventilation similar to that suggested for shell molding in Figure IV-9. A sidedraft hood can be used to remove smoke and vapors from the hot cores as they emerge from the equipment and are cooled [190].

3. Hot-Box Binders

Hot-box binders, resins that polymerize in the presence of acid salts or acid anhydrides and liberate heat to form a binder, are blends of three types of resins: furan, phenol-formaldehyde, or urea-formaldehyde resins [75,201]. Core blowing, core shooting, and curing and cooling hot-box cores may result in exposures to furfuryl alcohol, formaldehyde, and CO. Metal pouring may result in exposures to CO and hydrogen cyanide, depending on the formulation [7,201].

"High" concentrations of formaldehyde were measured in an English foundry that used hot-box binders [203] (specific concentrations were not given). In this foundry, the hot-box process was carried out on two multi-stage machines (a four-station and a six-station machine). Each mold was brought to a filling station, revolved around the back of the machine, and finally brought to the front of the machine for core removal. The curing time was 3-5 minutes at 200-250°C (392-482°F). At the six-station machine, an air velocity of 2.25 feet/sec into the exhaust hood was measured at the delivery point, from which the cores were then passed along a conveyor belt fitted with a canopy hood. After 5 minutes on the conveyor belt, the warm cores were taken out to remove minor blemishes by hand filing. There was no exhaust ventilation at this point, and insufficient time for core cooling was allowed before finishing the cores. The workers were exposed to 10 ppm (12 mg/m^3) of formaldehyde during this operation.

At the four-station machine, the air velocity into the hood at the delivery point was 1.1 feet/sec; no provision was made for removing fumes from the hot cores as they were placed on racks beside the machine to cool. The worker who removed and stacked the cores was exposed to up to 5 ppm (6 mg/m^3) of formaldehyde. It was concluded that control of emissions at the machines may not be sufficient because certain types of cores continue to generate formaldehyde as they are stacked and placed on conveyor systems or when blemishes are removed by hand. For this reason, exhaust ventilation is necessary during these operations [203].

Engineering controls for hot-box coremaking were described in the NIOSH foundry hazard technology study report of 1978 [7]. Cores were made in a room containing seven high-production horizontal-type hot-box core machines. Core constituents were of silica sand, red iron oxide, core oils, and catalysts containing urea and ammonia. The coremaking sequence consisted of core blowing and curing, core ejection and removal from the box, core finishing, core removal from the rack, inspection, and placement of cores on the storage rack. In addition to handling the cores, the operator cleared excess materials from the corebox with an air nozzle after the cores were removed.

However, the operator did not directly remove the core from the box. Rather, the core was ejected onto a lift-out rack, which indexed through four positions. After the corebox opened, the lift-out rack received the cured cores at the first position. It was then indexed to a second position where the cores were given a light finishing. The rack paused at the third position and, finally, the cores were indexed to a fourth position in front of the operator for unloading. The entire indexing cycle took about 1 minute.

Emissions were controlled by an overhead canopy hood above the core machines, operator station, and core storage racks and by an individual fresh air supply for each worker. The lowest edge of the canopy was 7.6 feet (2.3 meters) above floor level. An air exchange of 9,500 cubic feet per minute (ft^3/min) (4.5 m^3/s) provided an updraft velocity of 40 ft/min (0.2 m/s) into the hood. A flow-splitter baffle within the canopy proportioned the exhaust, drawing the greatest amount from the corebox that generated the most emissions. The baffle helped to control the fumes from entering the breathing zone (see Figure IV-11).

Most emissions occurred during and for a short period after the opening of the box after curing. Because of the 1-minute period between corebox ejection and removal of the cores by the operator (during which cooling

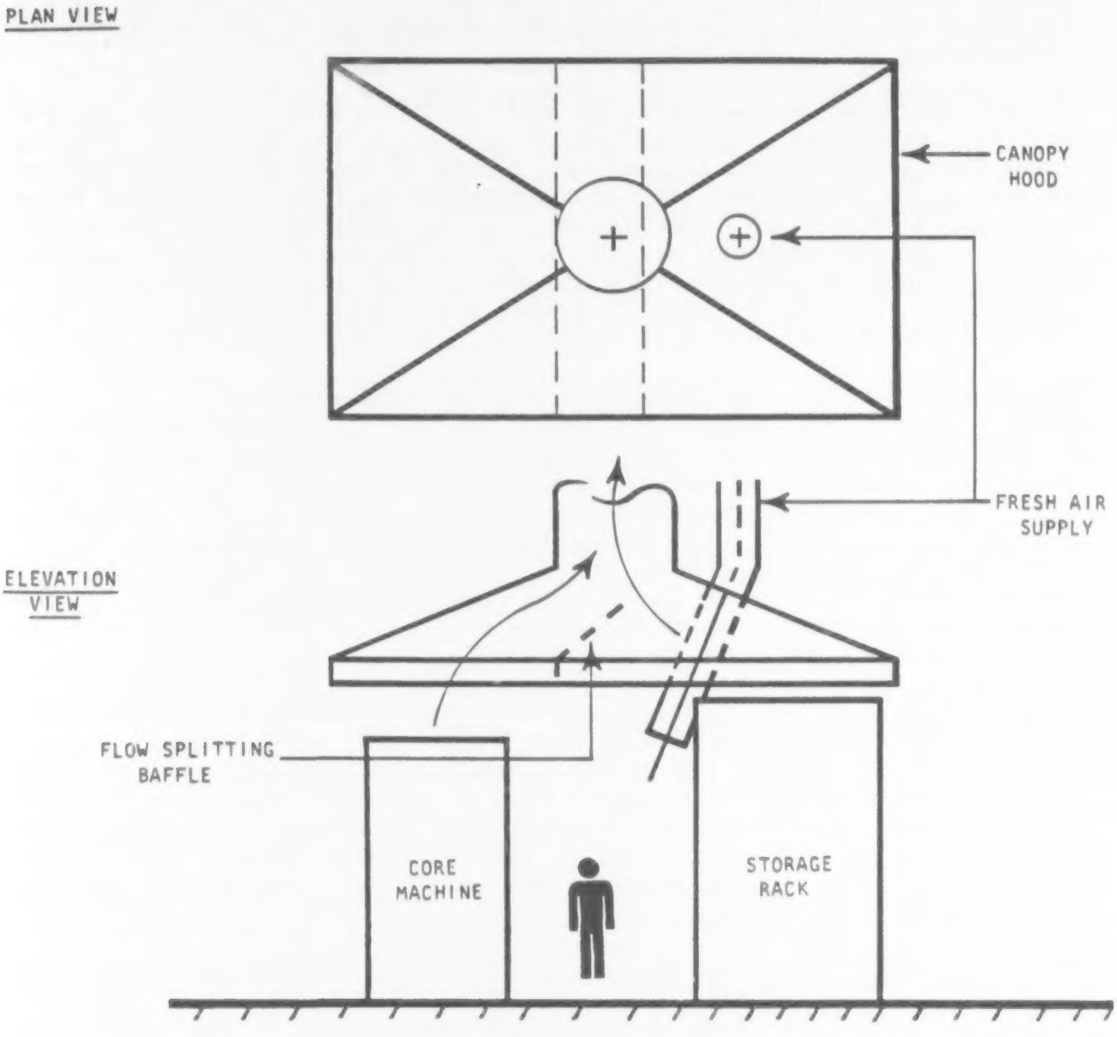

PLAN VIEW
CANOPY HOOD
FRESH AIR SUPPLY
ELEVATION VIEW
FLOW SPLITTING BAFFLE
CORE MACHINE
STORAGE RACK

FIGURE IV-11. Canopy hood and fresh air supply for furan hot-box core machine

Adapted from reference [7]

and degassing of the cores took place), few air contaminants were emitted during handling. The engineering controls used, successfully held the airborne concentration of gases, vapors, and respirable crystalline silica well within the permissible exposure limits [7].

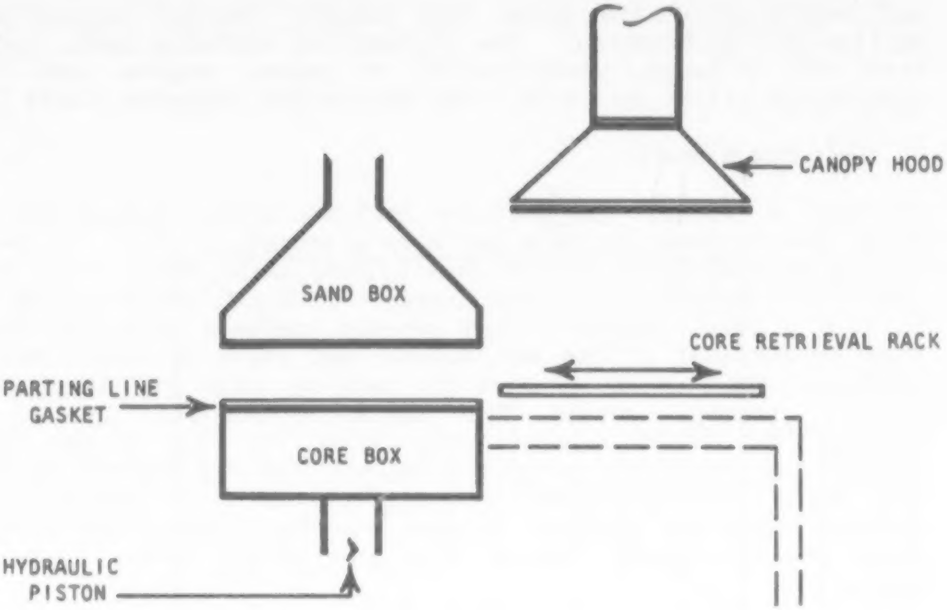
4. Cold-Box Binders

In 1967, a two-part polyurethane cold-box binder system was developed which uses a phenolic resin and a polyisocyanate [13]. In the presence of a gaseous catalyst, either dimethylethylamine (DMEA) or triethylamine (TEA), the phenolic resin and diphenylmethane diisocyanate (MDI) combine to form a strong binder. This process presents potential hazards not only as a result of the MDI solvent and resin materials but also the catalysts (DMEA or TEA). Area air samples taken in the coreroom of a ferrous foundry showed TEA concentrations of up to 32.4 ppm (134 mg/m^3), which exceeded the OSHA PEL of 25 ppm (100 mg/m^3) [154]. The catalyst's gaseous emissions from the process can be removed from the workroom atmosphere by a properly designed exhaust system which captures both the catalyst emitted from the freshly made cores and the gases under pressure leaking from poor seals in the corebox blowing system [7].

Air MDI, phenol, and TEA/DMEA concentrations were monitored in 25 to 28 iron and steel foundries where urethane binders were used in no-bake and cold-box core and mold-making processes. In none of the 90 samples collected at stations using phenolic urethane no-bake did the phenol concentration exceed the OSHA PEL of 5 ppm (19 mg/m^3); in a few cases when hot sand was used, the formaldehyde concentration did exceed 3 ppm. Of the 210 air samples collected for phenolic urethane at cold-box coremaking stations, only 25 exceeded the OSHA PEL of 25 ppm for TEA. The higher concentrations were usually associated with leaking fittings, use of excessive amine catalyst, or inadequate corebox seals and were readily corrected by improved engineering controls [204].

Examination of engineering controls for phenolic urethane cold-box core production were included in the NIOSH foundry technology studies [7]. In one operation studied, the core machine used was a vertical press-type consisting of a stationary sand hopper and attached matchplate and a vertical piston with a matchplate that opened and closed the corebox (see Figure IV-12). An automated core liftout rack moved the cores from the corebox to the worker position. The coremaking cycle consisted of automatically blowing, gassing, purging, core ejecting, retrieving, and storing the cores on racks. Core constituents consisted of lake sand and a two-part binder system of phenolic and isocyanate (MDI polymer) resins, with TEA gas used as the catalyst. The gases were controlled by using a negative pressure at the discharge side of the corebox. The exhaust gases were incinerated by an afterburner before being discharged into the atmosphere. A sidedraft hood was located at the corebox, and a canopy hood was over a setoff bench. By using a setoff bench, the core (or mold, in other cases) was removed from the corebox and immediately placed on the setoff bench for

SIDE VIEW


CANOPY HOOD
SAND BOX
CORE RETRIEVAL RACK
PARTING LINE GASKET
CORE BOX
HYDRAULIC PISTON

FRONT VIEW

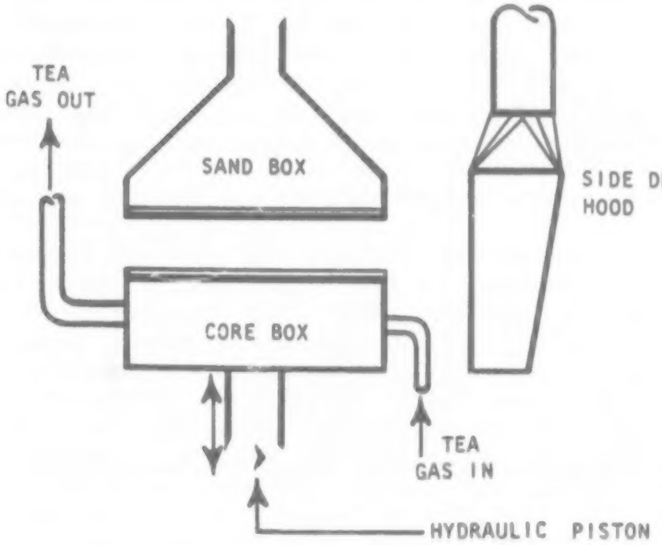

TEA GAS OUT
SAND BOX
SIDE DRAFT HOOD
CORE BOX
TEA GAS IN
HYDRAULIC PISTON

FIGURE IV-12. Cold-box coremaking exhaust

Adapted from reference [7]

1-2 minutes under a hood. The exposures of core machine operators to gases, vapors, and respirable silica were well below OSHA PEL's or NIOSH REL's [7].

In a second operation, exposures to TEA or DMEA in cold-box core production were evaluated. Emission sources in the coremaking area included gases leaking at corebox seals (parting line gaskets, blow seals, and stripper pin o-rings) and gases emitted from cores during handling and finishing. When seals were inadequate, dilution ventilation and exhaust of gases within the corebox were not effectively controlling TEA emissions; concentrations approached the OSHA 8-hour TWA PEL of 25 ppm (100 mg/m^3). Recommendations for reducing leaks included providing adequate vents in the pattern for TEA to be uniformly released [7].

5. No-Bake Binders

No-bake binders are a more recent development in the foundry industry and because of the reduced heat requirements have become increasingly attractive in the energy-shortage-conscious United States [13]. These binders are basically modifications of the processes previously described. Emissions generated from the binders in the no-bake process, as with other coremaking and molding processes, depend on the resin and catalyst composition, the sand quality, and the temperature [13,201]. No-bake cores successfully reduce the potential for heat stress in the coreroom.

In 1976, Virtamo and Tossavainen [205] surveyed 10 Finnish iron and steel foundry coremaking areas for gases formed from the furan no-bake system. The furan system was used at about 2% of the furan binder and 1% of phosphoric acid, based on the weight of sand. A total of 36 furfuryl alcohol and 43 formaldehyde personal samples were taken. Phenol concentrations were measured in one foundry (six samples) and phosphoric acid concentrations in two foundries (nine samples). The mean furfuryl alcohol concentration was 4.3 ppm (17 mg/m^3), with 22% of the measurements exceeding the Finnish furfuryl alcohol TLV of 5 ppm (20 mg/m^3). The highest furfuryl alcohol concentrations (10 to 40 ppm) occurred in areas where workers were filling and tucking large coreboxes. The mean formaldehyde concentration was 2.7 ppm (3.3 mg/m^3).

Workers who were filling large coreboxes were exposed to the highest formaldehyde concentrations (5-16 ppm or 6-20 mg/m^3). The highest phenol concentration measured was 0.35 ppm (9.3 mg/m^3), while the phosphoric acid concentrations were <0.1 mg/m^3 [205], both of which were well below the OSHA PEL's of 5 ppm (19 mg/m^3) and 1 mg/m^3, respectively [55]. Furfuryl alcohol was determined by the Pfalli method, formaldehyde by the Goldman and Yagoda method, phenol by the 4-amino-antipyrine method, and phosphoric acid by the molybdenic blue method [205].

Concentration of air contaminants was measured during a NIOSH HHE at a two-stage, furan no-bake core process in an iron foundry [206]. The first stage involved the construction of a large core and required 10-15 minutes; the second, the core cure stage, required 45 minutes. The substances used in the process included a mixture of furfuryl alcohol and paraformaldehyde, a phosphoric and sulfuric acid mixture, and sand. These substances were mechanically mixed and were poured into the mold, usually at room temperature; however, in cold weather simulation the sand was heated before mixing. Since the sand is not uniformly heated, some portion may become hot, and, when mixed with other substances, more vapors may be released.

Formaldehyde and furfuryl alcohol breathing-zone air samples were collected during normal conditions operating the day of sample collection and during simulated conditions that could occur on cold days. The furfuryl alcohol concentrations measured were 2.2 ppm during normal conditions the day of sampling and collected over a complete core production cycle (1-hour); 8.6 ppm under normal conditions and during the core preparation time only (15 min.); 10.8 ppm during the core preparation when the sand was heated to a warm condition (15 min.); and 15.8 ppm during the core preparation when the sand was hot (15 min.). The formaldehyde concentrations measured were 0.07 ppm during normal conditions over a complete core production cycle; 0.08 ppm during a complete cycle when the sand was warm and 0.33 ppm during the core preparation only when the sand was hot.

Charcoal tube air samples, using an MSA personal monitoring pump, were collected in an iron foundry where no-bake resin cores and molds were produced [207]. The materials used in the cores and molds were sand, a base resin (1.5% based on weight of the sand) containing furan resin, furfuryl alcohol, and some urea-formaldehyde resin, a catalyst (0.23%) containing toluene-sulfonic acid, isopropyl alcohol, and water. These ingredients were mixed in an automatic mixer and then poured into wooden molding forms. The 8-hour TWA-exposure concentrations of furfuryl alcohol were 6.25 ppm (25 mg/m^3) in the breathing zone of a coremaker and <6 ppm (<20 mg/m^3) in the breathing zones of an assistant coremaker and an apprentice. The highest value was 66 mg/m^3. None of the workers had any of the signs or symptoms considered to be attributable to furfuryl alcohol, i.e., ocular irritation, headache, nausea, or dizziness. It was concluded that furfuryl alcohol levels up to 66 mg/m^3 were not hazardous; this is consistent with the NIOSH REL level of 50 ppm (200 mg/m^3) of furfuryl alcohol as a 10-hour TWA (based on a 40-hour workweek) [86].

Recommended engineering controls for no-bake binders include (1) using binders free from or containing <0.5% free formaldehyde; (2) using new or reclaimed sand at 20-25°C (68-77°F) of such purity that it does not emit volatile material when treated with acid; (3) using catalysts that do not contain volatile solvents such as methanol; (4) using the lowest possible binder and catalyst content; and (5) placing functional exhaust ventilation fans along the mixer trough in a position so that the air can circulate away from the mixer trough and remove air contaminants from the work stations [208].

Although coremaking systems produce various types of air contaminants, ranging from silica dust to TEA gas, the free silica and chemical hazards resulting from coremaking operations can be effectively controlled by a combination of exhaust and supply air ventilation. Exhaust ventilation such as canopy hoods, sidedraft hoods, or specifically located flange exhaust duct openings should be used for controlling contaminants at coremaking machinery. Set-off booths or other similar controls for emissions releases while cores are cooling should also be used. Transferred fresh air directed at the operator can be effective in reducing negative plant pressures and worker exposures to emissions and in providing heat stress relief in coremaking operations that require heating [7].

6. Noise in Coremaking Operations

In addition to the hazards of dusts, fumes, gases, vapors, and heat present in coremaking, high noise levels create the potential for occupational hearing loss. In 1978, NIOSH [7] measured noise levels in a foundry coreroom, in which many styles and types of sand cores were made; this type of foundry was common at that time.

The most significant sources of noise in the core area were the fans, air nozzles, air exhaust from pneumatic equipment, pattern or mold vibration, gas jets, and noise from other shop operations. Efforts to reduce core area noise included the substitution of quieter equipment unless some other factor prevented their use, e.g., physical size. At stations where workers used air nozzles for pattern cleaning, several quiet air nozzles with sufficient force were tested, but only one model, which did not plug up with sand and dirt, performed the job both effectively and quietly.

Vibrators were used at most work stations to separate the sand core from the pattern. Piston-type vibrators were found to generate the loudest noises and often generated more force than was necessary. Turbine and rotary vibrators generated much less noise and generally had sufficient force to separate the sand from the pattern. Parting compounds, used to release the core from the pattern, reduced the overall noise levels in the area. Some type of pneumatic equipment was used on most of the machines. As a result, air exhausted at high pressure generated very loud noises, which contributed significantly to the overall noise exposure. Many types of commercially available exhaust mufflers performed adequately.

Noise exposure levels were measured for six different operators in the area who wore a noise dosimeter for 7-8 hours of a normal workshift. On the average, the noise levels in the coreroom were below the allowable OSHA PEL of 90 dBA as shown in Table IV-1, although some noise levels as high as 100 dBA were recorded. The results also suggest that binder substitution may be a method for reducing noise levels in the coreroom. Whenever noise levels in foundry corerooms exceed the NIOSH recommended 8-hour TWA of 85 dBA, engineering controls such as the substitution of less noisy equipment are recommended [7].

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TABLE IV-1. Coreroom noise levels

Process time**	ENL* (dBA)	Range (dBA)	Percentage of exposure					
			85-87	87-90	90-92	92-95	95-97	97-100
Core blower	88	87-100	0	13	61	20	4	2
Shell core No. 1	89	85- 92	69	30	1	-	-	-
Shell core No. 2	87	<85- 95	62	32	4	1	-	-
No-bake	82	<85- 97	5	2	1	1	0.5	-
Oil sand (bench)	86	<85-100	19	11	5	3	1	<0.5
Oil sand (bench)	83	<85-100	13	8	4	12	2	<0.5

*Effective Noise Level (ENL) = $90 + 16.61 \log \left(\frac{\%\ \text{count}}{100} \times \frac{\text{measure time}}{8\ \text{hr}}\right)$

**Based on 8 hours per day

Adapted from reference [7]

D. Melting

One of the major hazards common to foundry melting areas is molten metal splash which may account for approximately 25% of all occupational injuries occurring in melting and pouring areas [48,50]. To guard against such injuries, protective barriers should be placed wherever molten metal may splash on workers, and pits that allow for emergency molten metal spillage should be provided. Other hazards in melting areas are usually associated with the particular process equipment used. Hazards associated with metal melting varies with the type of melting equipment used and the composition of the melt.

1. Cupolas

Most of the cast iron produced in the United States is melted in cupolas [10,22,209]. Considerable quantities of both gaseous and particulate effluents are produced. The effluent production rate varies with blast rate, coke consumption, physical properties and composition of coke, type and cleanliness of metal scrap in the charge, coke-to-iron ratio, bed height, burden height, air heat temperature, and when the furnace is being charged with iron, steel, scrap, coke, and flux [210,211].

The gaseous emissions from cupolas consist mainly of CO_2, CO, SO_2, and nitrogen (N) [22]. Of these, SO_2 and CO are probably the most hazardous to foundry workers. Sulfur dioxide concentrations of 25-250 ppm (65-655 mg/m^3) by volume have been measured [211]. Carbon monoxide concentrations were monitored in the air at 52 iron, 5 steel, and 10 copper alloy foundries in Finland that used sand molding. About 1,000 area air samples were taken, and the same sampling sites and measurement times were used for each foundry. The workers' exposure was evaluated from 2-hour personal samples. The mean CO concentration in the breathing zone of casters was 85 ppm (98 mg/m^3), and 67% of breathing-zone samples of cupola tenders exceeded the Finnish and OSHA PEL of 50 ppm (55 mg/m^3), 8-hour TWA. The NIOSH recommended 8-hour TWA exposure concentration for CO is 35 ppm. Area CO concentrations around the cupola averaged 240 ppm (280 mg/m^3) and 110 ppm (127 mg/m^3) in the casting area [212].

Possible causes of cupola leaks and worker exposure to CO and other toxic gases are: (1) design restrictions in the stack above the charging door; (2) restrictions to gas flow caused by poor fitting of spark or dust arrestors or scrubbers; (3) stack location and failure to elevate the stack above adjacent structures (causing downdrafts); (4) the use of any charging device that momentarily restricts the gas flow from the stack; (5) leaks in the exhaust system on the pressure side of the fan; and, (6) insufficient ventilation of the gases coming from the cupola windbox when the blast air is turned off [184]. To provide adequate worker protection from CO, the cupola system must be designed to eliminate these problems. Uncontaminated makeup air should be provided, especially on the charging platform and in the area around the base of the cupola where CO concentrations of up to 0.1% have been measured. Sometimes CO is burned to CO_2 in an afterburner; if it is not burned, CO can present a potential health hazard to maintenance workers and a potential explosion hazard in pollution control equipment [23]. Carbon monoxide monitors are recommended to warn charging crane operators and workers on the charging floor of harmful levels of CO and thus protect against excessive CO exposure.

Carbon monoxide is also a hazard during cupola repair. Accidents can be prevented by proper confined-space entry and by providing CO monitoring alarms. Using sealed openings in the sides of the cupola stacks, adequate ventilation within the cupola, and a job crane and safety harness to ensure rapid removal of workers from the cupola in an emergency is recommended [213]. A special problem can develop during cupola repair when two cupolas are connected to a single common air pollution control system. Carbon monoxide can leak back from the used cupola into the unused one where repairs are in progress. A supplied-air respirator may be required in this situation.

Destructive distillation and volatilization of organic materials in the cupola may produce a complex mixture of potentially harmful materials [22]. An effective exhaust system for controlling cupola emissions requires two separate exhaust hoods, an exhaust from the top or near the top of the vertical combustion chamber, and a canopy over the tapping spout. Emissions from the top of the cupola are variable in temperature and amount of air contaminants; therefore, exhaust systems must be designed to provide sufficient indraft at the charge door to prevent escape of emissions under widely varying conditions [7].

The tapping spout, forehearth, and sometimes the charging door are other sources of in-plant atmospheric contamination from cupolas [183]. A canopy hood with side baffles and mechanical draft are recommended to control toxic metal fumes issuing from cupola spouts during tapping. Emissions occurring while workers tap the cupola are captured by a canopy hood if the exhaust flow is adequate. A minimum exhaust velocity of 150 ft/min (0.76 m/s) into all hood openings is recommended [190].

Safety hazards peculiar to cupolas include the possibility of falls from the charging deck into the cupolas and accidents in dropping the bottom. Accidents associated with dropping the cupola bottom can be avoided if: (1) bottom drops are performed with a long steel cable attached to a vehicle and all plant personnel are in a designated safe area; (2) the valve that controls the doordrop is relocated to a designated safe area where it can be manned at all times; and (3) audio and visual signaling; devices are installed around the cupola doordrop area to secure the area during drops [183,214].

During the cupola charging, the equipment used should be guarded to protect workers from accidents. When cupolas are mechanically charged, elevators, machine lift hoists, skip hoists, and cranes should be guarded to prevent material from dropping on workers in the area below. When cupolas are manually charged, a guardrail should be placed across the charging opening to prevent the operator from falling into the cupola [215].

2. Electric-Arc Furnaces

Direct-arc furnaces are used for melting steel and iron. The dense fumes, composed primarily of iron oxide, manganese oxide, and volatile matter from the charge scrap (such as oil, grease, and combustible products) that are emitted from the furnace during melting and tapping are best controlled by local exhaust [7].

Many existing arc furnaces employ overhead hoods with duct systems that are connected only during the melting cycle. Such systems require the use of roof ventilators above each furnace in conjunction with either distributed fresh air or enclosed and ventilated control rooms [7]. Some furnace hoods utilize mobile duct systems that provide exhaust during all furnace operations [24]. Interferences may occur, however, from the ladle hanger or overhead crane during the tapping process so that a sufficient amount of shrouding may not be available over the ladle to capture all the fumes carried in the thermal draft [24]. During charging and tapping, auxiliary canopy hoods may not completely capture emissions when high bridge cranes are used in the melting shops and if crossdrafts are present [7].

Fumes from electric-arc furnaces may also be controlled by using curtain walls. The curtain walls, however, limit the space from the roofline to the bottom chord of the roof trusses so that roof exhaust fans are needed to remove the contaminants from the confined space. This method is effective only in those cases where the contaminant has a tendency to rise quickly without spreading to any great extent, but it is not recommended if overhead crane cabs are on the same side of the bay as the furnace [7].

Electric-arc furnace noise can be reduced by an isolated control room. One such furnace operator's control room was located against one wall in one of the foundry's furnace buildings, about 10 feet (3 meters) from the furnace. All of the controls for the electric-arc furnace were located inside the room. Charging, adding alloying elements, and other operations were performed outside the room [7].

The noise attenuation of the control room and operator noise exposure were evaluated separately. Operator exposure was evaluated by comparing the noise exposure measured by a noise dosimeter worn by the operator with the noise exposure measured by a stationary monitor outside the control room. The attenuation of the room was evaluated by comparing the overall sound pressure level and the frequency spectra inside and outside the room. The data showed that the control room significantly reduced the noise exposure. Operator exposure inside the control room measured from 82-88 dBA and was therefore below the allowable OSHA PEL of 90 dBA for an 8-hour exposure. Outside the room, the noise level was above the OSHA PEL for 8 hours of exposure. The noise attenuation afforded by the control room was about 16 dBA. The baffling of the control room reduced the level of all frequencies above 20 Hz by 9-40 dB [7].

3. Electric Induction Furnaces

There are essentially three types of induction furnaces: the closed channel-type furnace, the open channel-type furnace, and the crucible or coreless induction-type furnace [216,217]. The major hazards that exist in foundries using induction furnaces are silica dust in charge bucket filling from scrap contaminated with silica; dust and gases during charge preheating; and metal fumes, dusts, and smoke in furnace operation [7]. Controls to prevent hazards include using clean and dry materials for melting, providing exhaust ventilation systems, and using shields or enclosing the melting operation [7]. The cleanliness and dryness of the scrap is necessary to keep the amount of dissolved gas in the metal low. Dry storage should be provided, or the charge should be preheated to 149°C (300°F) [216].

Emissions from an induction furnace can be successfully controlled by the use of a close-fitting exhausted furnace hood; if that is not feasible, general exhaust ventilation can be used. Close-fitting hoods are appropriate where the scrap contains lead, zinc, oil, and other contaminants and where the exhaust gases must be collected and cleaned before being discharged outdoors. General ventilation may be applied when: (1) the scrap is very clean and free from lead, zinc, and organic materials including oils; (2) the area above the furnaces is isolated by baffles and is exhaust ventilated; and (3) there are no disruptions to the thermal draft above the furnaces, such as crossdrafts through open doorways.

Close-fitting hoods are not necessarily effective in capturing all of the emissions throughout the entire furnace cycle, especially during furnace charging and tapping, and when they are used in conjunction with roof exhausters above the furnaces to provide general exhaust ventilation. Due to interferences from ladle hangers and crane cables, the portion of the hood that covers the pouring spout cannot be extended far enough to capture the fumes in the thermal draft from the hot ladle during furnace tapping. In addition, charge buckets used for furnace charging act as chimneys above the furnace, permitting fumes to escape the furnace hood. Fume exposure varies inversely with the boiling points of the metals present [7].

Defects of close-fitting induction furnace hoods are a common cause of fume emissions, especially during furnace tapping. To provide adequate breathing-zone protection during tapping, an overhead fan or mobile ladle hood may be required in addition to the furnace hood. Hoods that draw exhaust air into the furnace shell and across the hot metal require flow modulation during the melting cycle to prevent chilling of the furnace spout and the molten metal [7].

The making of solid aluminum castings in induction and other types of furnaces is complicated by the tendency of the metal to absorb hydrogen from the atmosphere and charge materials during melting and to form a tough oxide skin which is easily entrapped when the metal is poured. Fluxes and degassing agents can reduce melting fumes but have toxicity characteristics that must be considered. Fluxes should be dry because at high temperatures the presence of water in the flux increases the amount of fume produced. Fluxes are usually composed of chlorides or fluorides of the alkaline earth metals [218]. However, one type of flux contains, in addition to chlorides and fluorides, an oxidizing agent of either sodium sulfate or sodium nitrate. The temperature of the melt after mixing (approximately 1,000°C) may lead to the evolution of aluminum chloride fumes, together with some production of sulfur dioxide. Fluxes containing borofluoride and silicofluorides may form toxic gases, boron trifluoride and silicon tetrafluoride [184]. Because of inherent toxicity problems with metal fumes and fluxes, ventilation must be provided during these operations.

In addition to the fluxing procedure, it is customary to de-gas alloys by flushing the metal with a gas or by adding other materials that form a gas. The use of chlorine to de-gas light alloys is extremely effective, but because of its hazardous nature, caution must be exercised to safely introduce the gas into the melt. In addition, adequate ventilation must be available to dispose of the large volumes of hydrogen chloride produced [218]. Because of extreme toxicity of chlorine gas and its difficult handling techniques, tablets of chlorine-producing chemicals, usually hexachloroethane, should be used. Argon and nitrogen gas [184] are other degassing agents that can be substituted for chlorine. Nitrogen does not give rise to fumes but is less effective than chlorine [218].

E. Pouring Operations

After the metal is melted in the cupola or melting furnace, it is tapped or poured into a holding furnace or ladle. As the metal is discharged from the furnace, slagging (the removal of nonmetallic waste materials and metal oxides) is usually performed. Slagging operations are frequent sources of heat, hot metal splashes, metal fumes, dusts, and IR radiation. To control these hazards and the potential for burns, shields including radiant heat shields, exhaust hoods, and fresh air supply can be used [7]. Slag can be removed from a crane-transported ladle at a separate station where the workers are protected by a radiation shield with an opening large enough to allow the operation of a slag pole. Heat stress on the workers can be reduced by a fresh air stream directed to their backs, and metal fumes can be captured by a sidedraft exhaust (Figure IV-13).

Sometimes before the metal is poured, substances such as silicon, graphite, or magnesium are added to give the cast metal specific metallurgic characteristics [5]. The hazards present during the inoculation process are metallic dusts and fumes, IR radiation, and heat stress. During inoculation, proper shielding and local exhaust ventilation are required to protect the worker. In-mold inoculation is being developed as a control method for ductile iron-pouring emissions. In this process, magnesium or a rare earth added in the gating system increases inoculant recovery and produces no fumes [219].

Pouring operations include the transporting of molten metal from the melting or holding furnace by ladle monorails, crane and monorail cabs, and manual methods and the pouring of molten metal from a ladle into the prepared molds [5]. For small castings, hand ladles and crucibles are used. For larger castings and extensive pouring operations, larger ladles supported by a hoist during pouring and moved by monorail or on a wheeled carriage are used. Ladles with large holding capacities (up to 70 tons) can be transported by overhead cranes, and a geared mechanism tilts them for pouring.

A wide range of air contaminants are produced by thermal decomposition of mold and core materials during and after pouring. In simulated foundry pouring conditions, using green-sand molds, it was found that the CO concentration could serve as an indicator of the general emission levels over time. Peak emissions occurred shortly after mold pouring with the emission rate decreasing gradually until shakeout when it suddenly rose again to a new peak [220].

Airborne materials generated from 12 common molding systems which were simulated under laboratory conditions in every case were found to contain CO concentrations above the OSHA PEL [72]. Most of the other emissions measured were generally at levels considered nonhazardous to worker health. Exceptions to this were the SO_2 levels in the phenolic no-bake process and the ammonia levels which in certain hot-box molding and coremaking processes were generated in sufficient quantities to be considered hazardous to health during prolonged exposure. Based on these laboratory results, it was speculated that if the CO concentration was controlled to safe levels through ventilation, the concentration of most of the other chemical contaminants would also be reduced to below their respective TLV's. Whether this would also hold true for actual foundry conditions has not been proven.

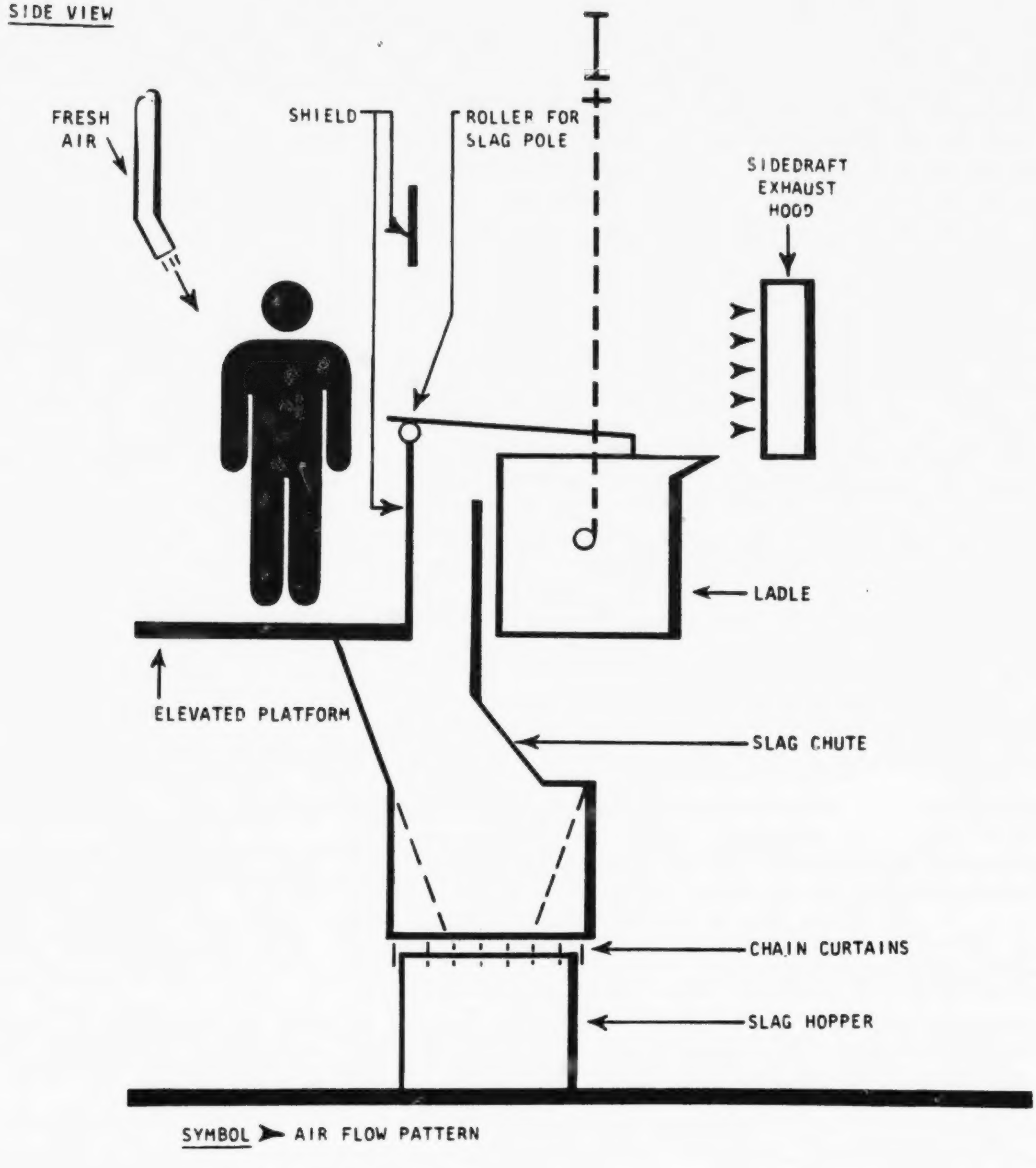

SIDE VIEW
FRESH AIR
SHIELD
ROLLER FOR SLAG POLE
SIDEDRAFT EXHAUST HOOD
LADLE
ELEVATED PLATFORM
SLAG CHUTE
CHAIN CURTAINS
SLAG HOPPER
SYMBOL ➤ AIR FLOW PATTERN

FIGURE IV-13. Slagging station

Adapted from reference [7]

Monitoring of the benzene-soluble fraction of total suspended particulates near pouring and furnace areas has shown measurable levels of benzo(a)pyrene, benzo(k)fluoranthene, benzo(a)anthracene, and pyrene and fluoranthene present near furnaces and pouring areas as well as in the cabs of cranes which frequently passed over the pouring areas [30]. These data (Table IV-2) suggest that when these potential carcinogens are present [175], engineering controls other than the general ventilation usually used for most pouring operations, especially in steel foundries, may be required.

Seacoal dust has long been used in foundries as an additive for mold sands to prevent "burn-on" on the casting surface, to aid in the separation of sand and casting at shakeout, to impart a good surface finish to the casting, and to reduce the incidence of expansion-type defects. However, the granular seacoal can contribute to the overall dirtiness in the foundry and introduce undesirable emissions including potential carcinogens into the foundry atmosphere during metal pouring. There are several coal dust substitute preparations based on, or containing, various combinations of synthetic polymers (polystyrene, polyethylene, and polypropylene), oils, asphalts (gilsonite and pitches), and bitumens which may be useful in reducing the carbonaceous dust in the sand preparation area and improve the overall cleanliness of the plant. However, the possibility that these

TABLE IV-2. PAH's near foundry pouring areas

	Unit	Furnace			Cranes		
		$\bar{X}$	Range	n	$\bar{X}$	Range	n
Total suspended particulates (TSP)	mg/m^3	3.75	1.80-5.78	10	1.76	0.58-3.04	25
Benzene-soluble fraction of TSP	mg/m^3	0.43	0.18-0.68	10	0.21	0.00-0.84	25
Benzo(a)pyrene	µg/m^3	0.139	0.107-0.172	2	0.085	0.024-0.149	7
Benzo(k) fluoranthene	µg/m^3	0.086	0.052-0.120	2	0.041	0.010-0.073	7
Benzo(a) anthracene	µg/m^3	0.049	0.031-0.067	2	0.038	0.008-0.065	7
Pyrene and fluoranthene	µg/m^3	0.053	0.040-0.066	2	0.052	0.034-0.117	7

$\bar{X}$ = mean
n = number of samples

Adapted from reference [30]

substitutes when heated may liberate potential carcinogens, even though they may be less carcinogenic than seacoal, has not been fully explored. Carbon monoxide production from molds after pouring under low temperature and nonreducing conditions may be reduced by 50% when coal dust substitutes are used [221].

Polystyrene has also been suggested as a coal replacement because of its effect on CO concentrations in the foundry. The average CO concentrations in the foundries studied which used coal dust were found to be about 350 ppm which was reduced to about 40 ppm after conversion to a polystyrene replacement. While these figures are averages and individual concentrations vary considerably depending on the foundry, they indicate that significant reductions in CO levels can be achieved by converting to polystyrene [222].

In addition to the hazard of various metal oxides, hydrocarbons, and destructive distillation emissions, the pouring operation is also one of the major sources of foundry heat. Although much of the heat in foundries is radiant heat from the hot molten metal and hot equipment, air temperature may also contribute significantly to the total heat stress on the foundry worker. Shielding or air-conditioned enclosures can significantly reduce radiant heat stress, especially during furnace tapping, pouring into ladles, transfer and pouring of molten metal and in holding furnaces.

The heat problem is usually severe during hot metal transfer using ladles manually pushed along a monorail, especially when one operator performs both the hot metal transfer and metal-pouring operations. Ladle covers and side baffles on ladle hangers, as well as fresh, cooled air distributed along metal transfer routes and protective clothing, can help to reduce the heat load. The supplied air should be used in combination with an exhaust system to remove contaminants from the pouring operation.

In mechanized casting lines in large iron casting foundries, a push-pull ventilation system is often used along the pouring line. Fresh air is blown towards the workers who are pouring metal into the molds and a large exhaust hood is on the other side of continuously moving mold lines. An effective pouring heat control, for a mechanized long pouring line producing ductile iron at the rate of 35 tons/hour, consisted of a supply-air rate provided behind the pourers of 52,000 ft^3/min (25 m^3/sec) and an exhaust rate on the opposite side of the flasks of 78,000 ft^3/min (37 m^3/sec). Air samples taken in worker breathing zones showed the concentrations of respirable crystalline silica, CO, organic vapors, and metal fumes to be below the OSHA PEL's [7].

General ventilation is often applied in open pouring floors [175]. As a dilution method, it is not effective at high emission rates during high production [7]. As new technology permits the foundry industry to increase production efficiency with increased mechanization, general ventilation will have a decreased application as a primary control for pouring and cooling processes. However, there will always be a need for general ventilation approaches where the lack of mechanization prevents the use of local exhaust systems, e.g., extra large casting operations and job shops pouring small runs in a variety of sizes and casting techniques. In general, only by controlling the emission at the source will ventilation be effective in preventing excessive worker exposures associated with pouring toxic metals that have low permissible exposure limits, e.g., lead, nickel, or copper. The need to control mold decomposition products at the source during cooling will depend on the organic materials present, as well as on variables such as pouring temperature, sand-to-metal ratio, cooling time, type and amount of binder, and production rate.

Another technique used to control mold emissions is to index the poured molds into a tunnel which is enclosed and exhausted. The operation can be performed from a control cubicle, thereby substantially reducing the potential for worker exposure to hazards [223].

F. Maintenance

One maintenance operation where workers may be exposed to high dust (including silica) and noise levels is the rebuilding of linings for the ladles used in handling the molten metal. During the curing of these linings, CO is produced from incomplete combustion caused by the premature cooling of the flames on the cool lining surfaces. To protect workers from exposure, an enclosure that has sliding doors to allow access for the placement and removal of the ladles can be used [7].

G. Knockout (Shakeout)

When the molten metal in a mold has solidified to a point where it will not distort when removed from the sand, the casting is removed from the flask in an operation called knockout or shakeout. Except for those molds produced without flasks or bottom boards, this procedure consists of opening the flask or mold frame and removing the casting. Usually the casting is then cleaned in the shakeout operation, which involves shaking off adhering sand and binder materials from the casting and sometimes breaking out the cores. The castings are then taken to the cleaning department and the flasks and sand are returned for recycling. These operations generally produce dust, and a green sand knockout gives off steam as well as dust. The shorter the interval between pouring and knockout, the larger the amount of steam but the smaller the quantity of dust liberated [188]. When the knockout process is performed at one location, local exhaust ventilation can be used to control the dust and steam [184].

The amount of dust and steam to be controlled will depend on several factors including the box size, the sand-to-metal ratio, the temperature of the sand, the casting size and configuration, etc. The types of exhaust ventilation that can be used to control the dust and steam are total enclosure, sidedraft, downdraft, and updraft. Care must be taken to prevent dust plugging when designing ventilation systems where steam and moist dust are involved. Recommended ventilation designs are presented in detail in Industrial Ventilation--A Manual of Recommended Practices [224], Recommended Industrial Ventilation Guidelines [190], and in Figures IV-14, IV-15, IV-16, IV-17.

Complete enclosure with ventilation is the best method of dealing with dust and fumes during shakeout, although access may become a significant problem. A complete enclosure has an opening on the inlet side for the entry of the molds and one on the discharge side for the removal of castings and boxes. The relatively small size of these openings allows the use of small volumes of air while still maintaining a high capture velocity at all openings.

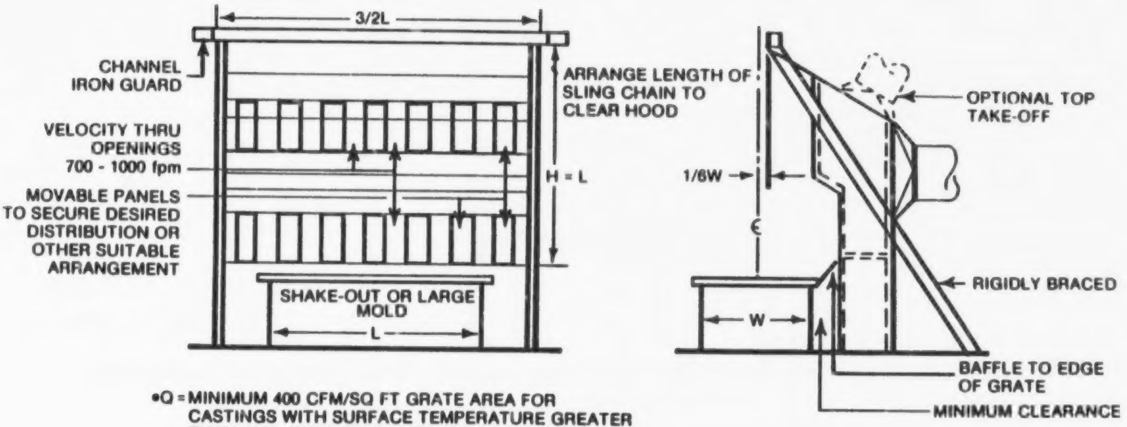
If sidedraft ventilation is applied, a hood mounted above floor level and alongside the knockout grid should be used. The opening should be mounted above the top level of the moldbox and on the side of the knockout that is remote from the operator's working position. The hood should be placed along the long side of the knockout, and the top of the hood should extend over the knockout line as far as practicable. The use of shields increases the effective capture capacity of the ventilation system. Screens may also be needed to control erratic drafts if the knockout grid is subject to random air movement, which would reduce the ability of the duct to capture dust, gases, and fumes. This type of exhaust will control only fine airborne dust and not the dust that falls with the sand into the hopper below the knockout.

The shakeout can be a major source of noise in the foundry. To control worker exposure to noise, the shakeout where possible should be isolated from the other processes by a total enclosure. An enclosure constructed of standard 4-inch (10 cm) thick acoustic panels can significantly reduce the noise levels. The accumulation of dust within an acoustical panel can reduce its sound absorption capacity.

In one foundry without the enclosure, the noise level permitted an allowable exposure of about 3 hours per day. With the shakeout enclosure, the overall noise level was reduced by about 16 dBA. Noise levels at the operator position were 89 dBA with the enclosure and about 105 dBA without the enclosure. The enclosure reduced the noise level of all the frequencies above about 100 Hz by 8 to 25 dB [7].

H. Cutting and Cleaning

In iron and steel foundries, after the shakeout operation, the sprue or pouring hole is knocked off or cut off and the castings are sorted and cleaned. The main hazard in this process is respirable silica dust. Dust can be controlled by using a conveyor belt made of a metal mesh with a downdraft exhaust system [7]. Control of torch cutting and arc-air gouging operations is not within the scope of this document but is discussed in the NIOSH criteria document on welding, brazing, and thermal cutting [225] and in the NIOSH foundry technology study [7].

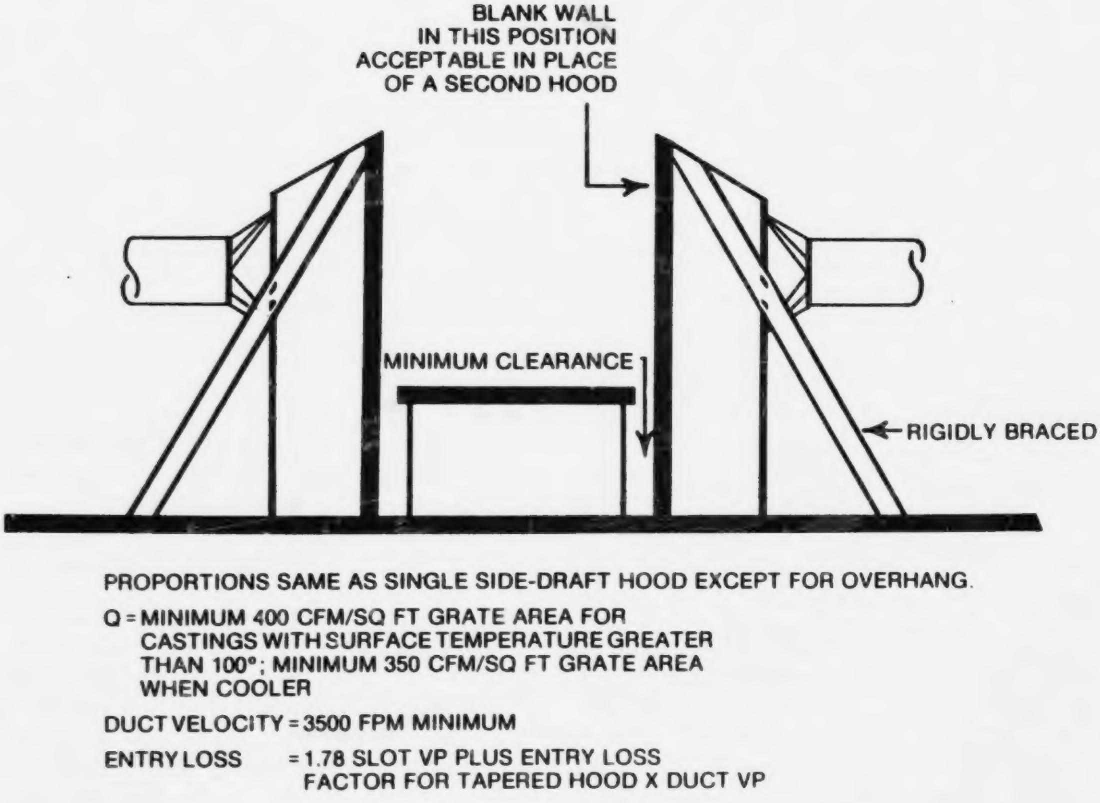

3/2L
CHANNEL IRON GUARD
VELOCITY THRU OPENINGS 700 - 1000 fpm
MOVABLE PANELS TO SECURE DESIRED DISTRIBUTION OR OTHER SUITABLE ARRANGEMENT
ARRANGE LENGTH OF SLING CHAIN TO CLEAR HOOD
H = L
SHAKE-OUT OR LARGE MOLD
L
OPTIONAL TOP TAKE-OFF
1/6W
W
RIGIDLY BRACED
BAFFLE TO EDGE OF GRATE
MINIMUM CLEARANCE

- Q = MINIMUM 400 CFM/SQ FT GRATE AREA FOR CASTINGS WITH SURFACE TEMPERATURE GREATER THAN 100°; MINIMUM 350 CFM/SQ FT GRATE AREA WHEN COOLER

- DUCT VELOCITY = 3500 FPM MINIMUM
- ENTRY LOSS = 1.78 SLOT VP PLUS ENTRY LOSS FACTOR FOR TAPERED HOOD X DUCT VP

FIGURE IV-14. Sidedraft hood

Adapted from reference [190]


BLANK WALL
IN THIS POSITION
ACCEPTABLE IN PLACE
OF A SECOND HOOD
MINIMUM CLEARANCE
RIGIDLY BRACED

PROPORTIONS SAME AS SINGLE SIDE-DRAFT HOOD EXCEPT FOR OVERHANG.

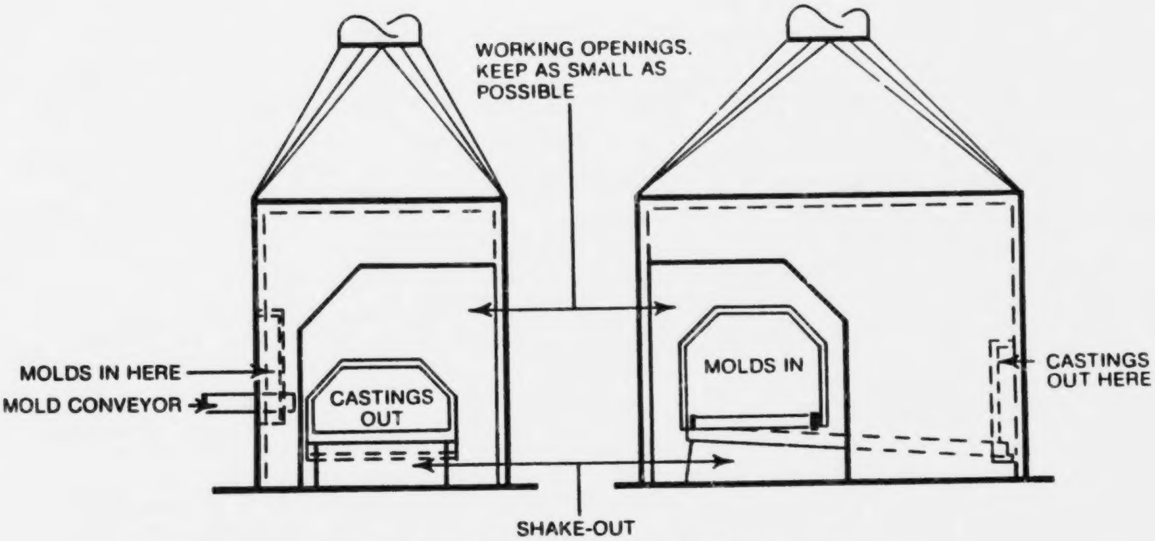
Q = MINIMUM 400 CFM/SQ FT GRATE AREA FOR CASTINGS WITH SURFACE TEMPERATURE GREATER THAN 100°; MINIMUM 350 CFM/SQ FT GRATE AREA WHEN COOLER

DUCT VELOCITY = 3500 FPM MINIMUM

ENTRY LOSS = 1.78 SLOT VP PLUS ENTRY LOSS FACTOR FOR TAPERED HOOD X DUCT VP

FIGURE IV-15. Double sidedraft hood

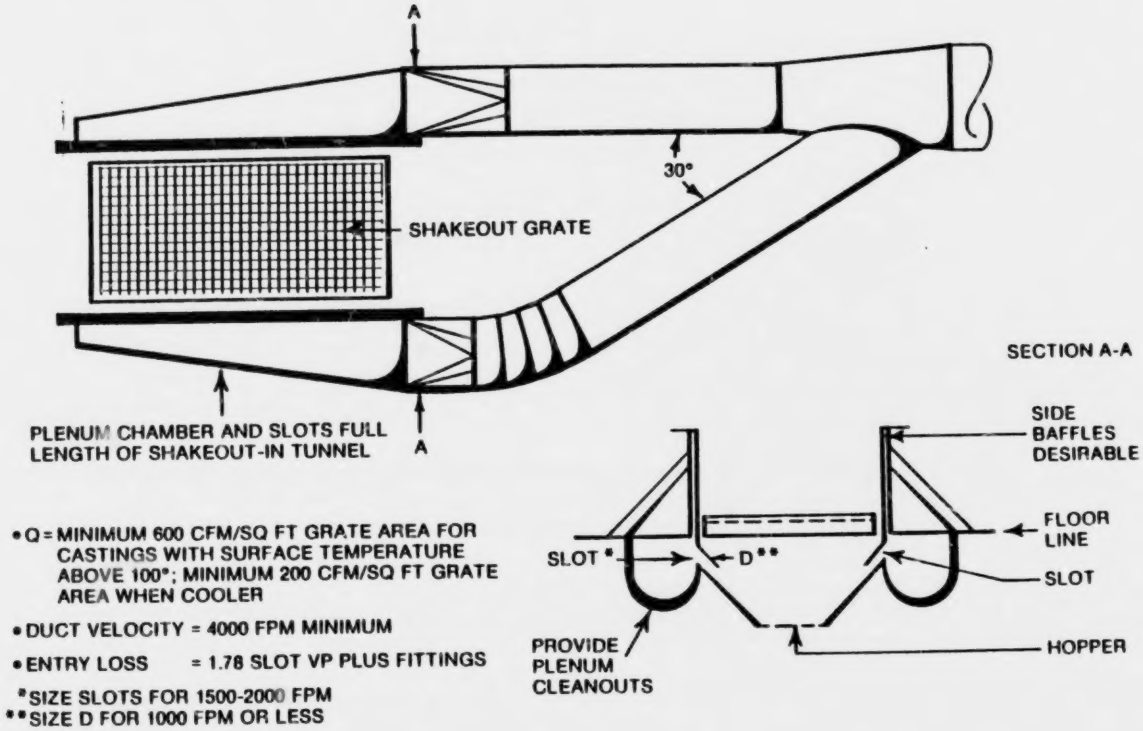
Adapted from reference [190]


WORKING OPENINGS. KEEP AS SMALL AS POSSIBLE
MOLDS IN HERE
MOLD CONVEYOR
CASTINGS OUT
MOLDS IN
CASTINGS OUT HERE
SHAKE-OUT

- Q = MINIMUM 200 CFM/SQ FT GRATE AREA FOR CASTINGS WITH SURFACE TEMPERATURE ABOVE 100°; MINIMUM 150 CFM/SQ FT GRATE AREA WHEN COOLER
- DUCT VELOCITY = 3500 FPM MINIMUM
- ENTRY LOSS = ENTRY LOSS FACTOR FOR TAPERED HOOD X DUCT VP

FIGURE IV-16. Enclosing hood

Adapted from reference [190]


A
30°
SHAKEOUT GRATE
PLENUM CHAMBER AND SLOTS FULL LENGTH OF SHAKEOUT-IN TUNNEL
A
SECTION A-A
SIDE BAFFLES DESIRABLE
FLOOR LINE
SLOT *
D**
SLOT
PROVIDE PLENUM CLEANOUTS
HOPPER

- Q = MINIMUM 600 CFM/SQ FT GRATE AREA FOR CASTINGS WITH SURFACE TEMPERATURE ABOVE 100°; MINIMUM 200 CFM/SQ FT GRATE AREA WHEN COOLER
- DUCT VELOCITY = 4000 FPM MINIMUM
- ENTRY LOSS = 1.78 SLOT VP PLUS FITTINGS

*SIZE SLOTS FOR 1500-2000 FPM
**SIZE D FOR 1000 FPM OR LESS

FIGURE IV-17. Downdraft hood

Adapted from reference [190]

Excess sand is removed from the castings by abrasive blasting operations and/or in tumbling mills. These operations produce high noise and dust levels. The engineering control of air contaminants in abrasive blasting booths is addressed in the NIOSH document, Abrasive Blasting Operations: Engineering Control and Work Practices Manual [226].

Tumbling mill noise has been measured in two different ferrous foundries [7]. In both cases, enclosures around the machines were used to protect workers from exposure to noise levels above 90 dBA. The tumbling mill operator was near the machines only during loading and unloading. Typically, the operator entered the enclosure, loaded one or both mills, started the cycle timer, and left the enclosure. After the cycle was completed or when convenient, the mill was unloaded and the cycle was repeated. The operator wore hearing protection while working in the enclosure. Tumbling mill noise exceeded the OSHA PEL's for an 8-hour exposure.

As a result of installing the engineering controls, noise levels in the casting, sorting, and inspection areas were reduced to below the OSHA PEL's. Without the enclosure, the allowable exposure time was estimated to be about 5 hours per day. The noise level inside the enclosure was about 105 dBA compared with 88 dBA outside. The enclosure reduced the noise level of all the frequencies above about 100 Hz by between 4 and 22 dBA.

Practical approaches to controlling dust in the cleaning operations after shakeout are to: (1) eliminate casting defects; (2) ensure that unnecessary cleaning operations are eliminated and essential ones are reduced to a minimum; (3) clean the castings as thoroughly as possible by abrasive blasting and tumbling operations before entering the cleaning room; and, (4) apply local exhaust ventilation to the cleaning operations [227]. Of the four considerations, the single most useful one to promote clean, healthy working conditions in cleaning rooms is to ensure that castings are cleaned as thoroughly as possible prior to entering the cleaning room.

Cleaning room workers are exposed to dust produced in the cleaning room itself, as well as to dust contamination from other foundry processes. Causes of increased background dust include (1) inadequate ventilation controls for chipping and grinding operations; (2) poorly maintained debris chutes from shot-sand separators on blast cabinets; (3) discharge of debris from sorting conveyors; (4) cleaning of castings with air nozzles; (5) operation of forklift trucks; (6) transfer of castings from hoppers into other hoppers or onto conveyors or benches; (7) use of hammers for gate, riser, and sprue removal from casting; (8) cleanout of swing grinder booths; (9) leaky seals on shot blast equipment; (10) sweeping with brooms; (11) throwing castings into sorting bins; and, (12) sand reclamation by clam bucket or crane. The accumulated airborne dust from all of these sources can result in high silica concentrations that may exceed the NIOSH REL and the OSHA PEL [7].

When elimination of dust production at the source is not possible, control of the dust by local exhaust ventilation is necessary. Methods for reducing the dust generated by hand-operated power-driven tools such as pneumatic chisels, portable grinders, and wire brushes include: (1) the castings may be cleaned on benches that are fitted with stationary sidedraft or downdraft local exhaust ventilation; (2) a mobile extraction hood may be used; (3) a low-volume, high-velocity ventilation system may be applied to the tool itself; and, (4) a retractable ventilation booth may be designed for castings too large for benches. Each method has advantages and disadvantages and one may be more suitable than the others in any given case. Local exhaust ventilation should always be used to control the dust produced by hand-fettling operations. Dust respirators and supplied-air hoods should be considered only when engineering controls are not practical [7,184].

Light castings can be dressed on benches fitted with exhaust air systems that can be applied to the bench itself. Although designs vary, the type of casting will probably determine the most suitable bench ventilation system layout. Portable hoods, although used in industry for many years, have the disadvantage that they must be placed close to the source of dust [184]. If the operator moves over a large area, constant hood adjustment is necessary. On the other hand, portable hoods can be used on work that is too large to dress on benches if the hood can be physically located near the grinding area. The low-volume, high-velocity system can effectively be applied to many dressing tools [184].

In a study of five foundries that used a combination of exhaust ventilation at the source of dust generation and a fresh air supply behind the worker for cleaning small to medium-sized castings, the breathing-zone concentrations of respirable silica were controlled below the allowable OSHA PEL's for a majority of workers. Limitations of the downdraft benches; portable hoods; high-velocity, low-volume ventilation on tools; and defects in applying the methods can result in incomplete dust control. Downdraft benches are ineffective in providing direct capture during processing of internal casting cavities and have limited capture efficiency during external finishing when the grinding swarf is directed away from the bench. The limitation of high-velocity, low-volume ventilation on tools is due to the interferences by some grinding hoods in certain operations; the lack of a practical hooding technique for chipping tools; the sensitivity of capture to tool position; the inconvenience of added air hoses for workers to handle; and clogging of high velocity, low volume inlet ports with dust [7]. When large castings (over 1,000 lbs.) are cleaned, local exhaust ventilation is not feasible or effective in most cases. In these instances, the use of air-supplied helmets or powered air-purifying respirators provides the most effective means of contamination control.

V. WORK PRACTICES

Ideally, foundry processes should be designed to: (1) eliminate all chemical and physical hazards such as toxic chemicals, heat, noise, and vibration; (2) control fumes, dusts, vapors, and gases in the workroom atmosphere; (3) prevent physical contact with toxic substances; and, (4) control safety hazards. If the ideal process design cannot be achieved, engineering controls such as local exhaust ventilation, noise damping materials, machine guarding, molten metal splash barriers, and radiant heat shielding can be employed to provide a healthful and safe working environment. However, some processes, the batch-type processes and manual operations, for example, may limit the application of engineering control strategies to these hazards. In such cases, work practices are required in addition to engineering controls to protect the workers.

An effective work practices program encompasses many elements, including safe standard operating procedures, proper housekeeping and sanitation, use of protective clothing and equipment, good personal hygiene practices, provisions for dealing with emergencies, workplace monitoring, and medical monitoring. Work practices are supported by proper labeling and posting and training all of which will serve to inform personnel of foundry hazards and of the procedures to be used to guard against such hazards. Good supervision provides further support by ensuring that the work practices are followed and that they effectively protect workers from the hazards.

A. Standard Operating Procedures

The most frequent work-related injuries to foundry workers are the result of strains and overexertion, contact with hot objects or substances, and being struck by or striking against objects [48]. Safe-operating procedures, if followed, can decrease the risk of these worker injuries. An evaluation of foundry accidents has shown that one of the major contributing factors in foundry injuries was lack of, or violation of, safe-operating procedures [213].

In the 1977 California report of injuries in iron and steel foundries, burns accounted for 25% of the injuries in the melting and pouring operations. Strains and overexertion injuries accounted for 43% of the injuries in molding and coremaking operations. Being struck by or coming in contact with objects accounted for 31% of the injuries in the cleaning and finishing operations [228]. In the 1981 Ohio foundry injury data, of all lost-time injuries, burns accounted for 12%, strains and sprains for 34%, and struck by or contact with an object for 32% [50].

A significant reduction in the incidence of burns can be achieved by proper handling of molten metal. One of the major safety considerations in the handling of molten metal is the control of moisture in the ladles or near the pouring operations. If water is vaporized by molten metal and if the vapor is trapped below the metal surface, the high water vapor pressure can cause an explosion [181]. Therefore, ladles and other devices used for handling molten metal must be kept dry at all times. In addition, pits required for slag ladles must also be kept dry, and they should be checked periodically to ensure that there is no moisture under the refractory material.

Batch processes used in many foundries for melting and pouring require periodic opening of systems, and proper safety procedures and work practices are essential to protect workers against injury. For example, in iron foundries that use cupola furnaces, safe procedures for supporting and dropping the cupola bottom must be followed. The cupola bottom should be supported by metal props of sufficient structural strength. The metal prop bases should be supported by sound footings such as concrete. Props should be adjusted to proper height and should be positioned in a safe area that will not endanger the worker. When dropping the cupola bottom, workers should be in a protected area or a safe distance from the furnace. One recommended method for dropping the cupola bottom is to use a block and tackle with a wire rope and chain leader wrapped around the posts or props that support the bottom doors. Workers can then pull the props out with the block and tackle while standing at a safe distance from the drop area. Before the bottom is dropped, the drop area should be inspected to ensure that no water has seeped under the plates or sand and that audible and visual signals have been activated [214,215].

A great deal of material is moved in foundries, including transporting large quantities of sand and molten metal, molds and cores, and castings. Manual handling of molds, molding materials, and castings is more frequent in small foundries than in large foundries where cranes, conveyors, and other types of mechanical equipment are commonly used [175]. For efficient production and personal safety, manual and mechanized materials handling should be performed according to safe standard operating procedures to prevent musculoskeletal injuries, hernias, overexertion, and traumatic injuries. Workers should be instructed in and practice the proper lifting techniques and should be encouraged to ask for help in lifting heavy objects. The National Safety Council's (NSC) publication, Accident Prevention Manual for Industrial Operations [182], the American Foundrymen's Society booklet, Safe Handling of Bulk Materials [229], and the NIOSH Work Practices Guide to Manual Lifting [230] offer instructions in proper methods for lifting and carrying loads.

Mechanical handling involves the use of lifting and hoisting devices, such as cranes and chain hoists, and of forklifts and conveyors for transporting materials [229]. Impact injuries most often occur from mishandling or from using mechanical devices in which suspended objects or materials may slip off hooks or accidentally fall off cranes, hoists, conveyors, or forklifts onto workers [181]. To reduce injuries while using forklifts and other lifting devices the following principles should be adopted: (1) the mechanical devices should not be loaded beyond their rated capacity; (2) workers should stand clear of loads; (3) suspended loads should always be attended; (4) overhead materials handling equipment should never be used for transporting personnel during normal operating conditions; (5) where molten metal is being handled overhead, crane operators should be instructed in the proper handling of the load; (6) crane operators should never pass ladles carrying molten metal or any other load over workers; and, (7) a warning gong or bell should be sounded to warn of cranes or materials-handling equipment approaching or passing overhead with molten metal [231]. These principles have been included in safety standards for sand castings by the American National Standards Institute (ANSI), the American Foundrymen's Society (AFS), and other foundry employer, manufacturer, and worker groups. Recommendations for handling molten metal and other standard foundry operating procedures are included in ANSI Z241.1-1981, Safety Requirements for Sand Preparation, Molding and Coremaking in the Sand Foundry Industry [192], ANSI Z241.2-1981, Safety Requirements for Melting and Pouring of Metals in the Metalcasting Industry [214] and ANSI Z241.3-1981 Safety Requirements for Cleaning and Finishing of Castings [232].

B. Housekeeping

Clean, unobstructed aisles and gangways, well-defined working areas, and adequate storage areas contribute to safe and healthful working conditions. Ignoring these factors may undermine the safety and health program. Housekeeping can also have a marked effect on production efficiency. Special attention should be given to: (1) storing raw materials and scrap in bins, compartments, or other appropriate forms of containment or separation; (2) providing a constantly maintained means of access for operations such as metal pouring; (3) removing items not required for immediate use from the foundry working area; and (4) providing and encouraging the use of specified areas for tools, lubricants, and other equipment [233].

To help reduce the incidence of injuries, floors should be made of concrete, brick, steel, iron plate, or other suitable material except in areas where the nature of the work requires refractory floors. In foundries where pit molding is performed, a refractory floor and a guardrail are required, but proper gangways should still be provided and constructed of concrete, brick, steel, or iron plate [231].

Foundry work areas should be cleaned as required to prevent accumulation of hazardous and nuisance dust. The preferred cleaning method is a vacuum system that delivers the dust to a collector system with an outlet pipe leading to the open air. The filter of any mobile vacuum cleaner should be highly efficient to minimize the amount of fine free silica and other dust particles that are returned to the atmosphere. Wet systems are also applicable. It is important to clean overhead plant fixtures, roof trusses, and hoists. Movement of poorly cleaned overhead cranes and hoists and the vibration of machines can cause dust to fall on workers. Good housekeeping requires an easy and safe access to overhead structures; this is sometimes difficult in older foundry structures [184].

The amount of cleaning that must be done can often be reduced if the spillage of sand and other dusty materials is reduced, e.g., in mechanized foundries, sand spills from overloaded conveyor belts can be avoided with proper engineering enclosures. Proper containers can reduce the amount of cleaning that has to be performed. It is also important to keep the roof in good repair to avoid water leaks that may lead to unsafe conditions in molten metal handling areas [7].

Another important consideration is lighting. The lighting in any foundry must be adequate to perform the jobs safely [175]. Lighting fixtures have to withstand a somewhat corrosive atmosphere, operate well in dusty conditions, and withstand high temperatures and vibrations. The cost-benefit advantages of capital investment in lighting are achieved through increased safety, greater productivity, better quality work, and greater job satisfaction for the worker [233,234].

C. Personal Hygiene and Sanitation

Personal cleanliness can play a significant role in protecting foundry workers from exposure to hazardous substances. This is especially vital in the coreroom area where skin irritation and sensitization or dermatitis may be caused by prolonged or repeated skin contact with resinous binders. Workers should be encouraged to wash their hands or other contaminated parts of the body immediately after skin contact and before eating or smoking to reduce the risk of ingestion or inhalation of toxic materials, e.g., lead. Abrasive skin cleaners and strong alkalis or solvents that defat the skin should be avoided. Smoking and eating should be prohibited in foundry work areas because cigarettes and food can become contaminated with toxic chemicals. Washing and showering facilities should be designed to avoid recontamination or reexposure to hazardous agents. Workers should be encouraged to shower after each workshift whenever possible. This will not only decrease the potential for worker exposure to toxic substances but will also reduce the probability of carrying toxic substances home to expose the foundry worker's family.

D. Emergency Procedures

Emergencies within foundry operations can greatly increase the risks of serious or fatal injuries and acute inhalation exposures to toxic substances. When fires, explosions, collisions, and other accidents occur, the two immediate concerns are (1) protecting workers from exposure; and (2) treating injured workers. The potential for release of molten metal further aggravates the hazardous conditions during emergencies. A warning system is necessary to inform workers of an emergency and to trigger an emergency action plan that has been developed and practiced in advance. Warning systems should include: fire alarms, area monitors to detect excessive airborne contamination such as CO alarms in and around cupolas, and alarms to warn workers of dangerous spills and cupola bottom drop. Each worker should be trained to recognize the significance of the alarms and to know the procedures to follow when a warning is sounded [235].

Protective clothing and escape equipment for use during evacuation from hazardous areas should be located in or near areas where emergencies may occur and should be accessible to workers and supervisors. Self-contained breathing apparatus with full facepieces should be available to provide workers with adequate oxygen and respiratory protection. Escape equipment is intended for escape use only; it is not adequate for extended protection or rescue work. Escape equipment should be maintained and inspected on a regular basis to ensure that it will be functional when needed [235].

Burns, scalds, eye and face injuries, lacerations, and crushing injuries frequently occur in foundries [48,50,51,176,181,228]. At least one person on each workshift should be formally trained in first-aid procedures to care for an injured worker until professional medical emergency help arrives or until the worker can be taken to a doctor. The emergency plan should also include procedures for transporting injured workers to a proper medical facility [235].

E. Maintenance

Equipment failures due to inadequate inspection and maintenance in foundries are often the cause of fatal and nonfatal injuries and exposures to hazardous airborne contaminants. Constant vigilance to ensure that all equipment is in safe condition and that operations are proceeding normally is critical to safety and to accident prevention. Adequate maintenance and immediate replacement and repair of any worn or suspicious equipment or component parts are essential. Inadequate training and experience in how to cope with emergency maintenance situations is often a major contributing factor in foundry accidents. Equipment design, construction, use, inspection, and maintenance are key goals for foundry safety [236].

Inspection and maintenance of ventilating and other control equipment are also important. Regular inspections can detect abnormal conditions, and maintenance can then be performed. All maintenance work should include an examination of the local exhaust ventilating system at the emission source. This may require testing for airborne chemicals or measurement of capture velocity [237].

Records of equipment installation, maintenance schedules, failures, and repairs can assist in setting up inspection and preventive maintenance schedules. This is especially important for hoists, cranes, ladles, and other process equipment that are used to handle molten metal. If equipment is inspected, repaired, or replaced before failures occur, the risk of injury is greatly reduced. In addition, adherence to a preventive maintenance schedule reduces equipment downtime. Equipment failure records can be used by management in making decisions about which types or brands of equipment to purchase and which will operate safely for the longest time.

The introduction of mechanized equipment to replace the manual methods in foundry operations has increased the risk of injuries to maintenance and setup workers of process machinery. An analysis of accidents in foundries has shown that, in many cases, injuries were related to unexpected energy release within the equipment, although recommended lockout procedures were in use [192,238]. The Foundry Equipment Manufacturers Association (FEMA) developed the concept of Zero Mechanical State (ZMS) to alleviate this problem [238]. On any given machine or process, ZMS takes into account the total energy pattern of the equipment and institutes appropriate measures to keep all energies affecting the industrial work area either at rest or neutralized during maintenance and repairs.

In the typical ZMS routine, each worker who may be involved is assigned one or more of each of the following: a lock, a key, and a lockout device, with the worker's initials or clock number stamped on each lock or on a metal tag attached to each lock. Before de-energizing equipment, the equipment operator should be notified that repair work is to be done on the machine. Electrical power is then turned off, the lockout devices are placed through the holes in the power handle and through the flanges on the box, and an individual padlock is placed on the lockout device. Others who may be working on the same equipment should add their individual locks to the same device. A "Man-at-Work" tag is placed at the controls, and the controls are checked to ensure that all movable parts are at rest. If pneumatic, hydraulic, or other fluid lines affect the area under maintenance, they should be drained or purged to eliminate pressure and contents and the valves controlling these lines should be locked open or shut, depending upon their function and position in the lines. Air valves should be vented to the atmosphere, and surge tanks and reservoirs should be drained. If lines are not already equipped with lockout valves, they should be installed [192,238].

Mechanisms that are under spring tension or compression should be blocked, clamped, or chained in position. Suspended mechanisms or parts that normally cycle through a lower position should be moved to their lowest position or blocked, clamped, or chained in place [192,238].

When the maintenance or repair work has been completed, each worker should remove the padlocks; the last person removes all lockout devices. No worker should ever allow anyone else to remove the locks. If the key to a lock is lost, the owner should report it at once to the supervisor and get both a new lock and key. In some cases, equipment can be tagged out instead of locked out. However, tags are not as effective as locks because tags are easily removed, overlooked, or ignored [238].

F. Monitoring

1. Foundry Airborne Contaminant and Physical Hazard Monitoring

As described in Chapter III, foundry operations, especially those using silica sand and organic binders, may produce potentially hazardous materials, the nature and quantity of which may vary from one plant to another according to the type of foundry. Workplace monitoring is necessary to determine the existence and magnitude of possible hazards. Foundry work also presents various physical hazards, such as noise, heat, vibration, and radiation, that should be monitored to ensure safe and healthful working conditions.

An initial foundry plant survey should include an inventory of the substances present and their physical, chemical, and toxicologic properties. In addition to aiding management in the selection of protective measures, this information may be required by physicians treating exposed workers or by firemen fighting plant fires. Material safety data sheets, especially for resinous binder formulations, may not always contain adequate information [175]. Thus, the composition, properties, and hazards of the mixtures or materials may not be known or may not be available when needed.

The survey should follow the raw materials as they are processed throughout the plant and should identify locations of suspected hazards. Nonenclosed operations such as mulling, mixing, pouring, shakeout, and cleaning should be the primary environmental monitoring areas. Potential fire, explosion, and runout areas should be identified so that emergency procedures, including escape and rescue routes, can be determined. Noise, heat, and other physical hazards should also be evaluated. Melting, molding line, shakeout, and cleaning room operations should be the focus of an initial plant survey. Finally, any changes in processing methods, in plant equipment, in products, and in quantities and types of materials used and stored all affect foundrymen's potential exposure to chemical and physical hazards.

After the plant survey, areas where potentially significant exposures may occur should be sampled to determine the levels of chemical and physical hazards present in the working atmosphere. Personal sampling can provide a measure of engineering control effectiveness in containing foundry emissions and physical hazards and can indicate work practices and protective equipment that are necessary to control further exposures. NIOSH criteria documents on hazardous substances that may also be present in foundries have recommended the frequency of monitoring for contaminants or physical hazards. These documents should be consulted to establish a sampling schedule that will adequately describe the working environment. Sampling and analytical methods for foundry hazards are presented in Appendix D.

Workplace monitoring data should be recorded, maintained, and reviewed as necessary to improve engineering controls, to evaluate medical and training needs, and to determine the extent and frequency of use of personal protective devices. In addition, the correlation of airborne contaminant concentration and worker exposure data with medical examination reports may be very useful in identifying and assessing exposures.

2. Medical Surveillance

A foundry is a very complex working environment that is hot, noisy, dusty, and strenuous. The worker may be exposed to a wide range of chemical substances in various physical forms and to physical hazards which affect both health and safety. The potential synergism of co-existing hazards is not completely known. The object of medical surveillance of foundry workers is to ensure the workers' health and physical well-being, at work and away from work, both in the short- and the long-term. The preplacement medical examination allows the physician to assess the applicant's physical, mental, and emotional capabilities and as far as possible, match these with work requirements, responsibilities, and risks. Furthermore, it provides baseline medical findings against which subsequent changes can be compared. Medical and environmental monitoring data should be available to the worker as specified in 29 CFR 1910.20 [141].

a. Preplacement Examination

(1) History

The medical history should include medical, work, social, family, and smoking histories, with special attention to any history of previous occupational exposure to chemical and physical hazards.

(2) Clinical Examination

The preplacement examination should ascertain the worker's general fitness to engage in often strenuous and hot work, as well as ability to react quickly and rationally to any potentially dangerous situation that might arise. The physical examination should include a complete examination of the cardiovascular and respiratory systems with x rays, cardiovascular and pulmonary function tests, measurements of height and weight, a urinalysis, a complete blood count, and an estimate of physical fitness and work capacity.

Special attention should be given to the skin, including the ability to sweat freely, and sensitivity to irritants and sensitizers that may be encountered in the foundry. Old scars, in particular those which appear to have been caused by burns, should be noted. Workers who will use vibrating tools should be asked if they have symptoms of Raynaud's phenomenon, and their fingers should be examined.

Because of the heavy lifting and carrying requirements, special emphasis should be placed on the history of previous back and musculoskeletal problems, and the clinical examination for signs of lumbar spine abnormalities, restricted movement, or muscular spasm. The general consensus in the published literature is that preplacement lumbar x-ray screening has little, if any, value in predicting whether a worker will or will not develop back problems [230].

Because most foundry workers will be exposed to some fibrogenic dust, free nasal breathing is an important defense mechanism, and a normal functioning respiratory system is essential. Pulmonary sensitizers may be present in the work environment and their effect on a worker with an allergic susceptibility should be anticipated.

The eye hazards to which foundry workers are liable to be exposed include irritating dusts and fumes, foreign bodies of dust or metal particles, and UV radiation. Safety for most foundry workers depends upon good visual acuity and a full field of vision. Certain jobs may require full color vision. The safety of many may depend upon the visual distance judgment of crane drivers, slinger operators, and truck drivers.

(3) Special Examinations and Laboratory Tests

A full blood count and urinalysis may be indicated by the worker's history of past exposures or as the result of the clinical examination.

Pulmonary function tests of FVC and FEV_1 will provide an adequate baseline in most cases, but the physician may require additional measurements.

A posteroanterior, 14 x 17 in (36 x 43 cm) chest x ray should be taken and kept as part of the medical record.

Most foundry workers are liable to be exposed to noise intensities exceeding the present standards. A preplacement audiogram of all foundry workers is recommended.

Other medical examination recommendations are presented in the NIOSH documents listed in Appendix E.

b. Periodic Medical Examination

An annual periodic medical examination should be available to each worker. Its purpose should be to detect, as early as possible, any change in health which may or may not be due to occupation and which may or may not affect the worker's fitness to continue in a particular job. Through this examination, trends in health changes may be detected which may suggest a need for environmental control of a known hazard or of a previously unrecognized hazard or potential hazard.

An essential part of a periodic medical examination is the physician's interview with the worker. Confidence and good rapport must be established so that very early and even nonspecific symptoms may be elicited, which may then alert the physician to guide the subsequent clinical examination beyond the normal routine.

For the past 50 years, attention has been drawn to the presence of respiratory diseases in foundrymen throughout the industrial world. Despite the improvements in dust control methods in foundries that have become available, and generally applied, the problem of pneumoconiosis remains [34].

The chest x ray is the most specific means of diagnosing pneumoconiosis. The preplacement chest x ray may guide the physician in assessing fitness for foundry work; it may also reveal abnormalities that might later confuse or complicate the interpretation of any subsequent lung tissue changes [34]. The International Labour Office (ILO) stresses the importance of radiographic technique in the detection of early pneumoconiosis. High-speed and miniature films are not recommended. Films should be interpreted expertly according to the ILO U/C International Classification of 1980; although the "short" classification might be useful for clinical purposes, films that are used for epidemiologic or other studies should be read and recorded by the "complete" classification [102].

Although periodic chest x rays are routinely recommended for monitoring workers exposed to respiratory hazards, there is evidence, particularly with silicosis, that radiographic appearance does not necessarily correlate highly with ventilatory capacity [33,34,54,239]. There is a lower incidence of silicosis in younger foundry workers and in those who have been exposed fewer years [33,34,118]. Although presumably relatively short but massive free silica dust exposures can lead to severe disablement and death, such exposures are not likely to occur today. However, routine radiological chest monitoring of foundry workers is desirable [34]. Under reasonable foundry conditions, chest x rays at 3-5 year intervals should be adequate for young workers. Older workers, workers with 10 years or more of exposure, and those previously employed in dusty jobs should have chest x rays at more frequent intervals (1-3 years). Foundry workers with evidence of pneumoconiosis should have annual chest x rays. The physician may choose to change the frequency of chest x rays based on clinical impressions of individuals or on evidence of overexposure in particular foundry jobs, e.g., sandblasting.

Epidemiologic studies suggest an association between exposure to airborne hazards in foundries and an excess risk of lung cancer [30,31,40]. Other data, gathered from vital statistics, support the conclusion of an excess lung cancer mortality among foundry workers [31,42,43,127]. When taken individually, the data do not prove a causative relationship, but the overall evidence is strongly suggestive that working in a foundry is associated with an excess risk of developing lung cancer. Because routine chest x ray and sputum cytology do not readily detect bronchiogenic carcinoma at early stages, they are not currently recommended as part of regular medical surveillance for lung cancer in foundry workers.

During the periodic medical examination, the skin, eyes, and back should also be reexamined to note changes from the previous examination. The epidemiologic studies do not support an increased hazard of cardiovascular disease in foundry workers, and the standard 12-lead electrocardiogram is not of much practical value in screening or monitoring for nonsymptomatic cardiovascular disease. The symptoms elicited by the physician on interview, with respect to angina, breathlessness, and symptoms of chest illnesses, are likely to be of more value.

Similarly, with those handling vibrating tools, the physician's specific inquiries into cold, numb, blanched, or blue fingers are most useful in preventing substantial impairment from being suffered by even the vibration susceptible individual. Recommended engineering controls, medical surveillance, worker education, work practices, and personal protective equipment are contained in NIOSH current intelligence bulletin #38, Vibration Syndrome [240].

Where exposures for which NIOSH has already recommended occupational health standards occur in a foundry, physicians are referred to the medical examinations recommended in previous NIOSH documents (see Appendix E).

G. Other Work Practice Control Methods

Recommended work practices, such as proper materials handling procedures, housekeeping practices, and use of personal protective equipment, must be accepted and followed by the worker as an aid in preventing exposure to airborne contaminants and physical hazards in foundries. Employers can encourage acceptance of work practice controls by alerting and informing workers of the health and safety risks associated with the various melting, pouring, coremaking, and cleaning operations. In addition, employers should support these work practices by providing proper supervision, labeling, posting of hazardous situations, and effective administrative controls.

1. Posting and Labeling

Posting conspicuous safety and health warning signs in appropriate areas within the foundry will inform workers of hazardous operations, warn them about protective equipment that may be required for entry to certain areas, identify limited access areas and emergency equipment and exits, and instruct them about specific operating procedures, e.g., maintenance or repair of process equipment. When maintenance that increases the potential for exposure is in progress, signs should be posted to inform workers that such operations are taking place, for example, when the cupola bottom is being dropped, signs should be posted warning of potential spills of molten metal and that the operation is in progress.

Labels describing contents should be placed on containers of hazardous materials being used in the foundry. This is especially important in corerooms where new binding systems have recently been developed and the hazards associated with them are unfamiliar to the workers.

All labels and warning signs should be printed in English and where appropriate in the predominant language of non-English-reading workers. Workers unable to read the labels and signs provided should be informed of (and should understand) the instructions printed on labels and signs regarding hazardous areas of the worksite. All signs and labels should be kept clean and readily visible at all times.

2. Training

Training and behavior modification are important components of any program that is designed to reduce worker exposure to hazardous chemicals or physical agents and risk of accidental injuries. Training must emphasize the hazards present, the possible effects of those hazards, and the actions required to control the hazards. This is especially important in foundries where the recognition of hazards such as crystalline silica and noise is difficult because there are no immediate or sudden effects. Without special training on the long-term health effects of exposure to workplace materials, on the methods to avoid exposure, and on the symptoms of exposure, foundry workers may inadvertently allow themselves to be exposed to potential hazards.

In a 1974 California study, it was reported that 8.3 of the 14.9 injuries per 100 workers in ferrous foundries could have been prevented by adequate safety and health training [228]. The largest proportion of job disabilities that were preventable by safety and health training and behavior modification involved materials handling, i.e., 35% of the total for ferrous foundries. Although much of the materials handling in foundries is automated, a considerable amount of manual lifting and transporting of heavy materials is done. Manual lifting and handling of castings and molds produced the largest number of injuries and illnesses. The second most frequent type of injury or illness preventable by safety and health training and behavior modification was handtool handling, which accounted for 6% of the total number of injuries in ferrous foundries.

A training program should describe how a task is properly done, how each work practice reduces potential exposure, and how it benefits the worker to use such a practice. The worker who is able to recognize hazards and who knows how to control them is better equipped to protect himself from exposure. Frequent reinforcement of the training and supervision of work practices are essential.

3. Supervision

To protect workers' health and safety in a foundry, it is essential for supervisory personnel to be aware of the potential risks to workers when proper work practices are not followed. Supervisors should be present to assure that proper procedures are followed during operations such as furnace charging and bottom dropping. Supervisors should also be prepared to direct other workers during emergency situations. Occasional checks should be made to verify that personal protective equipment and clothing are used properly. Supervisors should also be able to recognize exposures to hazardous materials and emissions, e.g., phenol and formaldehyde in the coreroom or CO around cupolas. One positive strategy for concerned management is to rate supervisory personnel on their understanding and implementation of safe and healthful work practices, in addition to other factors such as productivity.

4. Administrative Controls

Administrative controls are actions taken by the employer to schedule operations and work assignments in a way that minimizes the extent, severity, and variety of potential hazardous exposures. For example, only necessary personnel should be permitted to work in areas where there is a high risk of exposure. The duration of exposures may also be reduced by rotating workers between assignments that involve exposure and those that do not. Management and workers must be fully committed to the safety and health programs.

VI. PERSONAL PROTECTIVE EQUIPMENT AND CLOTHING

Where the engineering controls and work practices discussed in Chapters IV and V are inadequate to prevent illnesses and injuries, other protective methods must be considered. Personal protective equipment and clothing provide a means for reducing exposures to occupational hazards by isolating the worker from the physical hazards and airborne contaminants in foundries. Personal protective clothing and equipment, however, have their limitations and workers must be adequately trained in the proper use and maintenance of such items.

The use of appropriate, properly maintained personal protective equipment and clothing is essential to the safety and health of all foundry workers. The protective equipment and clothing used must be relevant to the hazard against which the worker is to be protected [7,226,241,242]. Improperly designed, maintained, and used equipment, in fact, can increase worker exposure to foundry hazards.

A. Protective Clothing

Protective clothing is essential in foundry operations where molten metal is used. In the 1973-74 State of California study [228], most of the burns and scalds which accounted for 27% of the "orders-preventable" disabilities could have been prevented if adequate protective clothing and equipment, especially for the hands and feet, had been in use. Of the burns, 58% resulted from contact with hot or molten metal or slag.

Protective clothing worn in foundries includes such items as gloves, shirts, trousers, and coveralls made of flame-retardant cotton or synthetic fabric; leather aprons, gloves, sleeves, and spats; aluminized suits or aprons used during melting and pouring operations for radiant heat protection; and air-supplied abrasive blasting suits for wear during cleaning operations. Because of the many types of protective clothing and equipment available, selection of proper protection should be carefully considered. Probably the most important criteria for selection are the degree of protection that a particular piece of clothing or equipment affords against a potential hazard and the degree to which the clothing and equipment may interfere with working safety and effectiveness. This should take into account the physical form of the hazard and, especially, the temperature of the material being handled [7,226].

B. Face, Eye, and Head Protection

Of the 520 "orders-preventable" injuries and illnesses in the California study [228], 28% were eye injuries other than those from welding flash. Most of the eye injuries could have been prevented had adequate eye and face protection been used by workers where the eye hazards were present. Half of these injuries occurred while workers were using machines or portable grinders that threw off metal fragments. Because eye injuries can occur in all foundry work areas, all workers should wear appropriate eye protection.

The Practices for Occupational Eye and Face Protection (ANSI Z27.1) provides guidelines and performance standards for a broad range of face and eye protectors [243]. Eye protection devices must be carefully selected, fitted, and used. If corrective lenses are required, the correction should be ground into a goggle lens. Goggles may be worn over ordinary spectacles, but they require cups that are deep and wide enough to completely cover the spectacles.

The three general types of equipment available to protect eyes from flying particles that may be encountered in operations such as chipping and grinding are: (1) spectacles with impact-resistant lenses; (2) flexible or cushion-fitted goggles; and, (3) chipping goggles. Where both side and frontal protection is needed, spectacles should have sideshields. Both flexible and cushion-fitted goggles are designed to provide frontal and side protection from flying particles. Most models will fit over ordinary ophthalmic spectacles. Chipping goggles, which have contour-shaped, rigid plastic eyecups, should be required in all grinding and cleaning rooms. Two styles are available: one for individuals who do not wear spectacles and one to be worn over corrective spectacles [182,243].

Eye protectors having mild filter shade lenses or polarizing lenses and opaque sideshields are adequate for protection against glare only. For conditions where hot metal may spatter and where visible glare must be reduced, a faceshield worn over mild shade spectacles with opaque sideshields should be specified [182,243].

Various types of faceshields are available to protect the face and neck from flying particles, sprays of hazardous liquids, and splashes of molten metal. In addition, they may be used to provide antiglare protection where required. Faceshields are not recommended by ANSI Z27.1 [243] for basic eye protection against impact. For impact protection, faceshields must be used in conjunction with other eye protection. For foundry furnace tenders and pourers, faceshield protection is necessary to guard against molten metal splashes and IR and UV radiation from hot metal and furnace areas. A metalized plastic shield that reflects a substantial percentage of heat has been developed for use where there is exposure to radiant heat [182].

Hardhats should be required to protect the head from possible impact injuries. In foundries, it is essential that head protection be worn when making furnace repairs or when entering vessels, especially cupolas. In addition to protecting workers against impact and flying particles, hardhats should be flame resistant and provide protection against electric shock [182,215].

C. Respiratory Protection

Respiratory protective devices vary in design, application, and protective capability. The user, supervisor, and employer must, therefore, be supplied with relevant information on the possible inhalation hazards present and other chemical and physical properties of the contaminants to understand the specific use and limitations of available equipment in order to assure proper selection [182,244,245,246,247].

Respiratory protective devices are tested and approved by NIOSH and the Mine Safety and Health Administration (MSHA) for protection against a wide range of inhalation hazards, including highly toxic atmospheres and those containing nuisance dusts. OSHA requires the use of NIOSH/MSHA-approved respirators. Testing and approval of these respirators are subject to conditions in 30 CFR 11 [248].

In addition, 29 CFR 1910.134 states that respirators shall be selected on the basis of the hazards to which workers are exposed [141]. The revised NIOSH respirator decision logic should be used for guidance in the selection of respirators [141]. The criteria for selecting respirators depends on a safe exposure limit and other chemical and physical properties of the contaminant. If sufficient information regarding the properties of the contaminants and the specific use conditions cannot be obtained, the selection of a suitable respirator may not be possible [182,245,247,249].

Because of the inherent airflow resistance in respirators, pulmonary function capability must be assessed in evaluating whether a worker can use a respirator. Respirators approved under 30 CFR Part 11 have inhalation resistances varying from 12 to 102 millimeters of water and exhalation resistances varying from 15 to 25 mm of water; these respirator performance specifications are for normal, healthy men. In the case of a self-contained breathing apparatus, the weight of the equipment also makes the respirator difficult to use. If a worker's cardiovascular or pulmonary function is impaired, wearing a respirator may constitute an unacceptable risk due to breathing resistance or the weight of the respirator apparatus itself [245]. Air-supplied respirators, still causing breathing resistance, are lightweight and widely and effectively used under conditions where the operator is not required to move beyond a limited range.

For the respirator to remain effective, a respirator maintenance program should be established in all foundries. Respirators should be sanitized daily and should be cleaned, inspected, and repaired as needed. In addition, OSHA requires, as part of 29 CFR 1910.134, proper maintenance and storage of respirators. Proper care will help to protect against dust, sunlight, extreme cold, excessive moisture, and damaging chemicals. The OSHA regulations include limited specifications as to the manner in which maintenance, cleaning, and storage requirements should be accomplished [245].

Adequate time should be devoted to servicing and inspecting respiratory protective equipment so that the filters, cartridges, valves, and the respirators themselves can provide the protection for which they were designed and certified. If practical and feasible, it is preferable to have a central respirator servicing facility, operated by a worker who has been thoroughly trained to service and inspect respirators [244,246]. A central respirator servicing facility can reduce the amount of management surveillance required and provide uniform respirator servicing. However, if only a few respirators are used, each worker can maintain their own respirator, and time should be allotted for servicing. If workers service their own respirators, an inspection program operated by a supervisor should be instituted [245].

It should not be assumed that wearing a respirator affords total protection against all contaminants. Workers should be informed about respirator limitations, such as the difficulty in obtaining a proper skin-respirator seal and that air-purifying type respirators for dust and solvents do not provide oxygen. Providing training in the proper fitting, care, use, and limitations of respirators should be considered as important as providing the respirator itself [245]. The workers should be informed that respirators should not be used in lieu of appropriate industrial hygiene practices and engineering controls.

Misuse can be minimized by establishing written procedures for respirator selection, cleaning, and use and by properly supervising all aspects of a respirator program. The written procedures as required by 29 CFR 1910.134 should contain all information necessary to ensure proper respiratory protection. A description of the limitations of each device in protecting against different materials or concentrations helps the user or employer select the proper respiratory protection [245].

D. Hearing Protection

Prolonged worker exposure to excessive noise in foundry operations, as in any industry, can result in permanent hearing loss unless protective measures are instituted. Engineering controls should be implemented to reduce noise to acceptable levels, these were discussed in Chapter IV. When engineering controls are not feasible, it may be necessary to provide protection by the use of ear protectors. Noise control and hearing conservation programs should conform to 29 CFR 1910.95 [141].

The types of ear protectors available for foundry workers are earmuffs that fit over the ear, earplugs that are inserted into the ear, or combinations of the two. The acoustical effectiveness of ear protectors ranges from about 20 to 45 decibels with greater attenuation at the higher frequencies. Usually, ear plugs give better attenuation at the lower frequencies and ear muffs better protection in the middle to upper frequencies [250]. The combination of ear muffs and ear plugs provides greater noise reduction than either one alone (about 5 decibels) [250,251]. The need for proper fit and seal of any type of ear protector cannot be over-emphasized.

Acoustically, there is not much difference between the types of earmuffs available, except for the very lightweight versions which may not provide sufficient protection against low frequency sounds. Selection of a particular type of earmuff can be safely left to the workers themselves, provided the manufacturer's instructions are followed [246,247,251,252]. Where earmuffs are worn for entire shifts, comfort, durability, and effectiveness are important considerations. For example, prolonged exposure to intense heat may lead to earmuff distortion. In addition, perspiration and dust accumulation between the earmuff and the worker's face can cause skin irritation.

Earmuffs may not always be compatible with other personal protective equipment. For example, the temples of safety glasses may lift the earmuffs away from the head, permitting sound to reach the ear through the broken seal. When respirators are worn, their straps may make it difficult or impossible for a worker to wear earmuffs. The brims of safety hats must have adequate clearance above the earmuffs; otherwise, the protective action of the helmet is jeopardized. Besides the interference with safety glasses and hard hats, ear muffs may increase heat discomfort; they are bulky and harder to carry and store, and they have more parts to keep clean. On the other hand, ear plugs require careful fitting in order for rated attenuation to be obtained. Ear muffs are relatively simple to fit; whereas workers may insert the ear plugs carelessly and thus not receive full protection from the plugs [250,253].

Some nondisposable earplugs are less acoustically effective than earmuffs. Semirigid earplugs give a reasonable degree of protection provided they are the correct size and are fitted properly. Cleanliness of plugs is also important to avoid external ear canal infection; handling earplugs in the dusty foundries environment can present a hygiene problem [247,250].

Disposable earplugs reduce the risk of ear infection. Provided the manufacturer's instructions are followed carefully, disposable earplugs may give more protection than semirigid plugs because they mold themselves to the shape of the ear canal. Disposable earplugs are usually made of polyurethane foam or glass down, which has the texture of cotton wool. Dry cotton plugs, although easy to insert, provide little protection [250]. Under foundry noise conditions ear plugs have been reported not to provide their rated noise attenuation levels [168].

When selecting proper hearing protection, the need to communicate with other workers and to hear warning signals in many high noise environments must be considered. Communication is most significantly affected when the noise has high intensities in the speech frequency range. Hearing protection devices interfere with speech communication in relatively quiet environments where the noise does not raise the open-air speech threshold by 80 dB or more [254]. However, in noisy environments, earplugs or earmuffs should not interfere with, but may even improve, speech intelligibility because speech-to-noise ratios are kept nearly constant. The protected ear does not distort speech by the overloading caused by the high speech and noise levels [250,254].

The concept of blocking the ear to improve hearing in a noisy environment can be a difficult one for a worker to accept, and some workers may resist wearing protectors because of anticipated difficulties in communication, especially if the protector is first tried in a quiet environment. Hearing protectors with a filter, which allows the lower frequencies in the speech range to pass through while blocking the higher frequencies of foundry noise, may appear to have advantages. Some of these filter-type devices may provide better communication in quiet environments although their reliability has been questioned. However, the conventional insert- or muff-type protectors provide acceptable communication; in addition, they provide protection against high noise levels [250,254].

The assignment of responsibility for maintenance and supervision of hearing protective devices will depend on the number of workers using them; however, if possible, one individual or section should have responsibility for supplying and inspecting hearing protective devices. Usually, the same person or section in charge of all other personal protective equipment should be selected. However, the enforcement of the program should be the responsibility of the line supervisor in each working group. Selecting and fitting ear protectors, especially nondisposable earplugs, should be performed by a qualified medical person. Cleanliness of molded earplugs is very important. The user should wash them with water and mild soap whenever they are removed, at least once a day. Disposable earplugs should be formed and inserted only with clean hands to reduce potential for ear infections and should always be discarded after each day's use. Both disposable and nondisposable earplugs are small and may become misplaced or lost; therefore, replacements should be readily available.

In addition to ensuring the proper use of and providing maintenance for hearing protection devices, foundry employers should inform their workers of the benefits to be derived from hearing conservation. Workers should understand the purpose of ear protection, how to recognize (both occupational and nonoccupational) high noise sources, and how to correctly use ear protectors.

VII. OCCUPATIONAL HEALTH AND SAFETY STANDARDS FOR FOUNDRIES

A. U.S. Standards

The OSHA-promulgated general regulations that apply to all industries were adopted from consensus standards developed by a variety of private organizations, including the American National Standards Institute (ANSI). Although the general regulations are not directed specifically toward foundries, many of them are applicable to foundry operations. These standards cover walking and working surfaces, handling of flammable and combustible materials, means of egress, vehicle-mounted work platforms, medical and first-aid stations, fire protection, compressed-gas cylinders, guarding of portable and powered tools, electrical hazards, personal protective equipment, medical and first-aid requirements, and occupational and environmental controls. Specific standards in 29 CFR 1910 that apply to foundries are listed in Appendix F.

The OSHA PEL's covering airborne contaminants (29 CFR 1910.1000) prescribe exposure limits in terms of 8-hour TWA concentrations for a number of the chemical agents present in foundries [141]. These regulations were adopted from the 1968 TLV's developed by the American Conference of Governmental Industrial Hygienists (ACGIH). Exposure limits have also been recommended by NIOSH in various criteria documents. Exposure limits applicable to foundries, including OSHA PEL's, ACGIH TLV's, and NIOSH REL's, are presented in Appendix B.

In addition to exposure limits, other requirements have been used in standards for controlling hazardous chemicals in foundries. OSHA standards (29 CFR 1910) define requirements for environmental and medical monitoring, labeling, and recordkeeping, as well as exposure limits for many toxic chemicals [141].

Safety standards for sand casting have been developed by ANSI, under the sponsorship of the AFS and other foundry organizations. The standards were based on recommendations by a committee of foundry safety officers with broad experience in the types of accidents that have occurred in foundries. ANSI Z241.1-1981, American National Standard for Safety Requirements for Sand Preparation, Molding, and Coremaking in the Sand Foundry Industry [255]; ANSI Z241.2-1981, American National Standard for Safety Requirements for Melting and Pouring of Metals in the Metalcasting Industry [256]; and ANSI Z241.3-1981, American National Standard for Safety Requirements for Cleaning and Finishing of Castings [257] have been published. These consensus standards are limited to those safety aspects of the metal casting industry for which other general industry standards do not exist or are inadequate. Although the standards are primarily concerned with minimizing injuries of personnel working around equipment, they require that air contaminant concentrations in the operators' breathing zone do not exceed the TLV's and that controls be provided to reduce airborne contaminants below the TLV. Personal protective equipment and medical and environmental monitoring are not addressed by the standard.

The Foundry Health and Safety Guide series, published by the AFS [69], discusses potential foundry hazards by substance, OSHA PEL, and hazard and control procedures.

Under the Occupational Safety and Health Act of 1970, states may elect to have their own occupational safety and health compliance programs, provided they meet Federal approval. Michigan has developed a comprehensive safety standard for both ferrous and nonferrous foundries [258]. The standard incorporates general industry standards to the extent that they are relevant to foundry equipment or processes. The standard also covers personal protective clothing and equipment, control of toxic fumes and dusts, working surfaces, and the safe handling of scrap, molten materials, sand, lead, and caustic chemicals. Worker training, recordkeeping, and medical and environmental monitoring are not addressed. Some states having a large number of foundries, including Pennsylvania, Ohio, and New York, do not have standards that address foundry hazards separately.

The National Fire Protection Association (NFPA) has also developed recommendations relevant to the foundry industry [259]. In particular, NFPA Standards 86A, B and C, covering all industrial ovens and furnaces, present guidelines, rules, and methods applicable to safe operation of such equipment. These regulations do not cover toxic vapors, noise levels, heat stress, or furnace operation. Information is presented on safety control applications, such as lockout, fire protection for furnace areas, and maintenance procedures. The rationale for the entire standard indicates that most furnace or oven failures are due to inadequate operator training, lack of proper equipment maintenance, and improper application of equipment.

B. Standards in Other Countries

The United Kingdom (UK) has a series of regulations that are directly applicable to foundry operations. The Factories Act of 1961 [260], which consolidated many previous regulations, deals with hazards in many industries in addition to foundry-specific hazards, e.g., regarding lifting of castings and other heavy loads. Other regulations retained in the Act are applicable to foundries, including the Grinding of Metals (Miscellaneous Industries), Special Regulation 1950, the Blasting (Casting and Other Articles) Special Regulation 1949, The Iron and Steel Foundries Regulation 1953, and the Foundries (Parting Materials) Special Regulation 1950. The blasting, grinding, iron and steel foundry, and parting powder regulations were enacted because of the silicosis problem found in earlier studies. The regulation on parting powders bans the use of silica flour as a parting material for use on molds and cores.

Special UK regulations pertinent to foundries included the Nonferrous Metal (Metal and Founding) Regulations of 1972 [260]. These regulations cover sand and die-casting of nonferrous metals.

The most recent general standard adopted in the UK that has jurisdiction over foundries is the Health and Safety at Work Act of 1974 [261]. Specific parts of the regulation define employer's duties with respect to safety equipment, workplace cleanliness, emergency procedures, protection against dust and fume, and personal protective equipment. The Health and Safety at Work Act further includes worker training, notice and provision of proper supervision, and environmental limits applicable to the workplaces.

Additional recommendations for control of foundry hazards in the UK are made by the British Cast Iron Research Association (BCIRA). The BCIRA functions as a technical review organization for iron foundries and reviews and recommends practices in the industry based on literature and reports of injuries and illnesses from their member companies. The BCIRA publishes "Broadsheets" describing hazards in foundries, their sources, existing TLV's, and recommended means of control. These "Broadsheets" cover safety and health hazards such as binders, catalysts, CO, and molten metal handling.

Europe has few national regulations relating specifically to foundries [261]. General regulations concerning places of employment protect workers by applying maximum workplace concentration (MAC) values to chemical and physical hazards. The regulations for labeling serve to identify potential workplace hazards. Requirements specify that certain hazardous industries and facilities which have a large number of workers must employ a physician to care for personnel and a safety expert to monitor the environment.

In Germany, the Association of German Foundrymen (AGF) issues leaflets or guidelines on foundry hazards, which are equivalent to regulations [261]. The content is similar to the British "Broadsheets," but the BCIRA guidelines are voluntary. Subjects discussed in the AGF leaflets include design and operation of compressed-air supply for foundries, design of cupola dust-arrester systems, the handling of binders and mold coatings, and exposure limits for foundry noise [261].

The Province of Ontario, Canada, has adopted foundry regulations as part of the Industrial Safety Act of 1971 [262]. These regulations encompass performance criteria for foundry operations, e.g., minimum width of gangways for transporting molten metal and minimum ventilation requirements for local exhaust on grinding wheels. The use of personal protective equipment, general and local ventilation requirements, and building restrictions are specified for foundry subprocesses. Environmental and medical monitoring, worker training, recordkeeping, and TLV's are not included in the regulations.

The Province of Quebec, Canada, also has a regulation that specifically addresses foundries [263]. The regulation details work practices associated with processes and equipment, as well as the minimum requirements for safe equipment and work areas. ACGIH TLV's are included in the requirements. Requirements for worker training and medical and environmental monitoring are not included.

VIII. RESEARCH NEEDS

Proper assessment of health and safety hazards in foundries requires that further research be conducted to determine the health effects of the total foundry environment on the foundry worker and that more injury data be compiled and analyzed on the causes of accidents in foundries. Research in control and process technology is needed to reduce the risk of illness and injury to foundry workers.

A. Epidemiologic and Health Effects Studies

In recent years, most of the foundry epidemiologic studies have been conducted in Finland, Yugoslavia, and Great Britain. In the United States, however, a comprehensive epidemiologic study of foundry workers' health was conducted by Renes et al. in 1948-49 [115], and in 1978 a retrospective mortality study reviewed the death records of International Molders and Allied Workers Union (IMAWU) workers who had been members for at least 11 years [31]. Both of these studies reflect past foundry practices, such as the use of silica parting powders. To accurately assess the status of foundry workers' health, prospective and retrospective epidemiologic studies that examine a representative cross section of U.S. foundries and foundry workers are needed. Because of the respiratory hazards in foundries, any epidemiologic studies must also consider the effects of smoking habits and their relationship to occupational hazards and risks.

Many of the epidemiologic studies either reported only the health effects in ferrous foundry workers or did not distinguish between the health effects in ferrous and nonferrous foundry workers. Studies should be undertaken to determine whether the higher melting temperatures needed for ferrous alloys, which allow for the production of tridymite and cristobalite in core molds, result in a higher incidence of respiratory illness. Epidemiologic studies should be performed to determine whether a significant difference exists in the health of ferrous and nonferrous foundry workers.

The causes of injuries and the prevalence of these injuries in foundry worker populations have been cited in numerous studies. However, comparison of the studies is difficult because different criteria and terminology are used in reporting injuries. Research is required to develop a comprehensive foundry injury information and reporting system, with a consistent terminology, to analyze trends in the causes of injuries to foundry workers. Studies are needed to determine why injuries and accidents are so prevalent among foundry workers. Such studies should utilize a comprehensive ergonomic approach including behavioral, motivational, and socioeconomic factors. Definitive studies are needed to determine the effects of the interaction of foundry air contaminants, physical hazards, and work procedures on all aspects of worker health and safety.

In recent years, a number of non-silica sands, including olivine, zircon, and chromite, have been introduced as mold materials in casting processes. Even though some studies have been performed on these materials, further research is needed to determine their toxicity.

B. Engineering and Process Controls

The improvement of engineering controls and the development of process technologies to reduce worker exposures to hazards should have a positive impact on the health and safety of foundry workers. The control of casting and cleaning operations is difficult to achieve with the currently available ventilation controls. Further research, preferably on a controlled experimental basis, should be performed to determine whether a combination of existing and new or improved ventilation methods might be sufficient to achieve control of air contaminants in chipping and grinding operations and in shakeout. The high-velocity, low-volume ventilation control method should be further studied for foundry application because it has the potential for providing breathing-zone protection for cleaning room workers. Further research should also be undertaken to evaluate existing floorstand grinder hood techniques and to establish conditions under which controls can be achieved.

Metal penetration, which occurs during the pouring and cooling of castings, is a major source of silica dust exposure for workers removing excess metal and mold materials from the castings. Consequently, control of burn-on would reduce the amount of cleaning and finishing of castings and would, therefore; reduce worker exposure. Recommendations for further research on burn-on control should include the systematic examination of the factors that cause metal penetration, with special emphasis on the influence of the different base-sand compositions and the impurities in mold and core constituents and washes. Further research should be performed to develop mold coatings that resist metal penetration.

Controlling noise below 90 dBA in chipping and grinding operations is not possible with present methods. Further research should be initiated to investigate and document control solutions for all foundry noise problems.

The development and use of new foundry control and process technology, including new binder compositions, need to be closely monitored and assessed to determine possible human hazards. Processes, such as the Schumacher process used for sand handling, electrostatic fog techniques, and the molding unbonded sand with vacuum (the V-process), should be studied to decide their effectiveness in controlling exposures and to evaluate their economic feasibility. Alternatives, such as the use of olivine sand and other non-silica sand mold materials, should be investigated to determine whether they can be adapted to both ferrous and nonferrous foundries and whether a system for separating olivine and silica sand can be developed.

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X. APPENDICES

APPENDIX A. Glossary of Terms

ACID BOTTOM AND LINING	In a melting furnace, the inner bottom and lining composed of refractory materials that have an acid reaction in the melting process, e.g., sand, siliceous rock, ganister, or silica bricks.
AIR FURNACE	A reverberatory-type furnace in which metal is melted by the flame from fuel burning at one end of the hearth, passing over the bath toward the stack at the other end of the hearth. Heat is also reflected from the roof and side walls.
AIR RAMMER	Pneumatically operated ramming tool.
AIR SETTING	The characteristic of some materials, such as refractory cements, core pastes, binders, and plastics, to take permanent set at normal air temperatures (20-25°C, 68-77°F).
ALLOY	A substance composed of two or more chemical elements of which at least one is a metal; usually possesses properties different from those of the components.
ALLOYING ELEMENTS	Chemical elements constituting an alloy; in metals, usually limited to metallic or metalloid elements added to modify the properties of the base metal.
ANCHOR	Appliance for holding cores in place in molds.
ANNEALING	A process involving heating and cooling applied to alter mechanical or physical properties, particularly to reduce hardness. The term is also applied to treatments intended to produce a definite microstructure or to remove gases. Any annealing process will usually reduce stresses, but if the treatment is applied for the sole purpose of such relief, it should be designated as stress relieving.
ARBORS	Metal shapes embedded in and used to support either green or dry sand cores.
ARRESTER, DUST	Equipment for removing dust from air handled by ventilation or exhaust systems.
BAIL	Hoop or arched connection between the crane hook and ladle or between crane hook and mold trunnions.

APPENDIX A. Glossary of Terms--Continued

BAKED CORE	A core that has been heated through sufficient time and temperature to produce the desired physical properties attainable from its oxidizing or thermosetting binders.
BALL MILL	A mill in which material is finely ground by rotation in a steel drum along with pebbles or steel balls. The grinding action is provided by the collision of the balls with one another and with the shell of the mill.
BANKING THE CUPOLA	Keeping the cupola hot by adding coke charges when iron is not being melted in the cupola, such as overnight.
BASIC BOTTOM AND LINING	In a melting furnace, the inner lining and bottom composed of materials that have a basic reaction in the melting process, usually crushed, burned dolomite, magnesite, magnesite bricks, or basic slag.
BEDDING A CORE	Resting an irregular-shaped core on a bed of sand for drying.
BED HEIGHT	The measured height of the cupola bed above the tuyeres before the first metal charge is added.
BENCH	A frame support on which small molds are made.
BENCH MOLDER	A craftsman who makes molds for smaller type castings.
BENTONITE	A colloidal clay derived from volcanic ash and employed as a binder in connection with synthetic sands or added to ordinary natural (clay-bonded) sands where extra strength is required; found in South Dakota, Wyoming, and the South Central States.
BINDER	A bond, usually other than clay, that is added to foundry sand, such as cereal, pitch, oil, sulfite byproduct, etc.
BINDERS, PLASTIC OR RESIN	Thermosetting synthetic resin materials, usually phenol formaldehyde or urea formaldehyde, used as bonding agents for core sands. These materials are adapted to curing in all types of commercial baking equipment. Granular phenol formaldehyde resins are used in the shell molding process.

BLACKING	Carbonaceous materials such as graphite or powdered carbon which are usually mixed with a binder and frequently suspended in water or other liquids; used as a thin facing applied to surfaces or molds or cores to improve casting finish.
BLAST	Air driven into the cupola or furnace for combustion of fuel.
BLAST FURNACE	In ferrous metallurgy, a shaft furnace supplied with an air blast (usually hot) and used for producing pig iron by smelting iron ore in a continuous operation. The raw materials (iron ore, coke, and limestone) are charged at the top, and the molten pig iron and slag that collect at the bottom are tapped out at intervals. In nonferrous metallurgy, a shaft type of vertical furnace, similar to the type used for smelting iron, but smaller, is used for smelting coarse copper, lead, and tin ores.
BLAST GATE	Sliding plate in the cupola blast pipe to regulate airflow.
BLASTING	A process for cleaning or finishing metal objects by using an air blast or centrifugal wheel that throws abrasive particles against the surfaces of the workpieces.
BLAST PIPE	A pipe that carries pressurized air, usually the section between the blower or fan and the cupola windbox.
BOND STRENGTH	A binding property of foundry sand that resists structural change.
BRIDGING	Local freezing across a mold before the metal below solidifies; solidification of slag within the cupola at or just above tuyeres, or "hanging up" of a large charge piece.
BUCKET	A vessel such as a tub or scoop for hoisting or conveying materials. Types include elevator, clamshell, dragline, grab, loading, or dumping.
BUNG	A removable top section or roof of an air furnace.
BURDEN	A collective term of the component parts of the metal charge for a cupola melt.

APPENDIX A. Glossary of Terms--Continued

CAPTIVE FOUNDRY	A foundry that is part of a manufacturing establishment.
CASTING, CENTRIFUGAL	A process of filling molds by pouring the metal into a sand or permanent mold that is revolving about either its horizontal or vertical axis or by pouring the metal into a mold that is subsequently revolved before the metal solidifies.
CASTING, SAND	A casting produced in a mold made of green sand, dried sand, or a core sand.
CHAPLETS	Metal supports or spacers used in molds to keep cores or parts of the mold that are not self-supporting in their proper positions during the casting process.
CHARGE	A given weight of metal or fuel introduced into the cupola or furnace.
CHARGING DECK	The floor from which furnace charging is performed, located at or just below the charging doors.
CHILL	The addition of solid metal to molten metal in a ladle to reduce temperature before pouring; the depth to which chilled structure penetrates a casting.
CHIPPING OUT	The process of removing slag and refuse materials attached to the cupola or furnace lining after a heat has been run.
COKE BED	First layer of coke placed in the cupola. Also the coke used as the foundation in constructing a large mold in a flask or pit.
COPE	Upper or topmost section of a flask, mold, or pattern.
CORE	A preformed sand aggregate inserted into a mold to shape the interior or that part of a casting that cannot be shaped by the pattern.
CORE BLOWER	A coremaking machine where sand is blown into the corebox by means of compressed air.
COREBOX	A wood, metal, or plastic structure, having a cavity shaped like the desired core to be made therein.
CORE DRIERS	Supports used to hold cores in shape while being baked; constructed from metal or sand for conventional baking or from plastic material for use with dielectric core-baking equipment.

APPENDIX A. Glossary of Terms--Continued

CORE, GREEN SAND	A core formed from the molding sand and generally an integral part of the pattern and mold, or a core made of unbaked molding sand.
CORE GRINDER	Machine for grinding a taper on the end of a cylindric core or for grinding a core to a specified dimension.
CORE KNOCKOUT MACHINE	A mechanical device for removing cores from castings.
CORE WASH	A suspension of fine clay or graphite applied to cores by brushing, dipping, or spraying to improve the cast surface of the cored portion of the castings.
CRANE	A hand- or power-operated machine for lifting heavy weights. Types include electric, gantry, jib, or monorail cranes.
CRUCIBLE	A ceramic pot or receptacle made of materials, such as graphite or silicon carbide, which have relatively high thermal conductivity and which are bonded with clay or carbon and are used in melting metals; sometimes, pots made of cast iron, steel, or wrought steel. The area in the cupola between the bottom and the tuyere is also known as the crucible zone.
CUPOLA	A cylindric furnace lined with refractories for melting metal in direct contact with the fuel by forcing pressurized air through openings near the base of the furnace.
CUPOLA DROP	The sand bottom, bed, and unmelted charges dropped from the cupola at the end of a heat or production cycle.
CUPOLA DUST ARRESTER	A device attached to the stack of a cupola that removes dust and sparks from the outgoing gases.
DIRECT-ARC FURNACE	An electric-arc furnace in which the metal being melted is one of the poles.
DRAG	Lower or bottom section of a mold or pattern, originally called a nowel.
DROSS	Metal oxides in or on the surface of molten metal.
DRY PERMEABILITY	The property of a molded mass of bonded or unbonded sand, dried at 105-110°C (220-230°F) and cooled to room temperature, allowing passage of gases out of the mold during pouring of molten metal.

APPENDIX A. Glossary of Terms--Continued

DRY STRENGTH	The maximum compressive, shear, tensile, or traverse strength of a sand mixture that has been dried at 105-110°C (220-230°F) and cooled to room temperature.
FACING SAND	A specially prepared molding sand mixture used in the mold adjacent to the pattern to produce a smooth casting surface.
FETTLING	The process of removing all runners and risers and of cleaning off adhering sand from the casting; also refers to the removal of slag from the inside of the cupola (British).
FLASK	Metal or wood frame without a top or a fixed bottom that is used to hold the sand from which a mold is formed; usually consists of two parts, cope and drag.
FLOWABILITY	The property of a foundry sand mixture which enables it to fill pattern recesses and move in any direction against pattern surfaces under pressure.
FLUX	A material or mixture of materials that causes other compounds with which it comes into contact to fuse at a temperature lower than their normal fusion temperature.
FURNACE, RESISTANCE	A furnace that heats by the resistance of electrical conductors.
FURNACE, REVERBERATORY	A furnace having a vaulted ceiling that deflects the flame and heat toward the hearth or the surface of the charge to be melted.
FURNACE, TILTING	A melting furnace that can be tilted to pour the molten metal.
GATE	End of the runner in a mold where molten metal enters the casting or mold cavity; sometimes applied to entire assembly of connected channels, to the pattern parts that form them, or to the metal that fills them, and sometimes is restricted to mean the first or main channel.
GREEN PERMEABILITY	The ability of a molded body of tempered sand to permit passage of gases through its mass.
GREEN SAND	A naturally bonded sand or a compounded molding sand mixture that has been tempered with water for use while still damp or wet.

APPENDIX A. Glossary of Terms--Continued

HAND SHANK	A pouring ladle carried and used by one man.
INDIRECT-ARC FURNACE	An electric-arc furnace in which the metal bath is not one of the poles of the arc.
INDUCTION FURNACE	A melting furnace that utilizes electrical induction heat.
INOCULANT	Materials that, when added to molten metal, modify the structure and thereby change the physical and mechanical properties to a degree not explained on the basis of the change in composition resulting from their use.
KNOCKOUT	Operation of removing sand cores from casting; in investment casting, the process of jarring the mold to remove the investment and casting from the flask.
LADLE	Metal receptacle, frequently lined with refractories, used for trans- porting and pouring molten metal. Types include hand, bull, crane, bottom-pour, holding, teapot, trolley, shank, lip-pour, buggy, truck, mixing, and reservoir.
LADLE, BULL	A large ladle for carrying molten metal, usually designated as a transfer ladle.
LINING	The inside refractory layer of firebrick, clay, sand, or other material in a furnace or ladle.
METAL PENETRATION	A casting surface defect appearing as if the metal has filled voids between the sand grains without displacing them.
MOLD	The form, made of sand, metal, or any other investment material, that contains the cavity into which molten metal is poured to produce a casting of definite shape and outline.
MOLDING, PIT	Molding method in which the drag is made in a pit or hole in the floor.
MOLD WASH	Usually an aqueous emulsion containing various compounds, such as graphite, silica flour, etc., used to coat the face of the cavity in the casting mold.
MULLING	Process of mixing sand and clay particles by compressing, stirring, and rubbing actions.

APPENDIX A. Glossary of Terms--Continued

PARTING COMPOUND	A material dusted or sprayed on patterns or mold halves to prevent adherence of sand and to promote easy separation of cope and drag parting surfaces when cope is lifted from drag.
PARTING LINE	A line on a pattern or casting corresponding to the separation between the cope and drag portions of a sand mold.
PATTERN	A form of wood, metal, or other materials around which molding material is placed to make a mold for casting metals.
RAMMING	The operation of packing sand around a pattern in a flask to form a mold.
RUNNER	A channel through which molten metal or slag is passed from one receptacle to another; in a mold, the portion of the gate assembly that connects the downgate or sprue with the casting ingate or riser. The term also applies to similar portions of master patterns, pattern dies, patterns, investment molds, and the finished castings.
RUNOUT	A casting defect caused by incomplete filling of the mold due to molten metal draining or leading out of some part of the mold cavity during pouring; escape of molten metal from a furnace, mold, or melting crucible.
SAND	A loose, granular material resulting from the disintegration of rock. Sand refers to the size of grain and not to mineral composition. Diameter of the individual grains can vary from approximately 6 to 270 mesh. Most foundry sands are principally made up of the mineral quartz (silica) because it is plentiful, refractory, and inexpensive.
SAND, BANK	Sedimentary deposits, usually containing less than 5% clay.
SAND, DUNE	Windblown deposits of sand.
SAND MOLDING	Sands which contain over 5% natural clay; usually between 10 and 20%.
SAND, SILICA	Although most foundry sands contain a high percentage of silica, the term silica sand is generally reserved for those that show a minimum of 95% silica content. Many high grade silica sands will analyze better than 99% pure silica.

APPENDIX A. Glossary of Terms--Continued

SANDS, MISCELLANEOUS	Include zircon, olivine, calcium carbonate, black sands (lava grains), titanium minerals, etc.
SCRAP (METAL)	Metal to be remelted; includes sprues, gates, risers, defective castings, scrapped machinery, and fabricated items such as rail or structural steel.
SEACOAL	A term applied to finely ground coal that is mixed with sands for foundry facings.
SHAKEOUT	The operation of removing castings from the mold or a mechanical unit for separating the molding materials from the solidified metal casting.
SHELL MOLDING	A process for forming a mold from resin-bonded sand mixtures that are brought into contact with preheated metal patterns, resulting in a firm shell with a cavity corresponding to the outline of the pattern.
SLAG	A nonmetallic covering that forms on the molten metal from impurities contained in the original charge, some ash from the fuel, and any silica and clay eroded from the refractory lining. Slag is skimmed off prior to tapping the heat.
SLAG HOLE	An opening in the front or back of a cupola through which the slag is drawn off.
SNAGGING	A grinding process for the rough cleaning of castings.
SPRUE	The vertical channel connecting the pouring basin with the skimming gate, if any, and the runner to the mold cavity--all of which together may be called the gate. In top-poured castings, the sprue may also act as a riser. Sometimes used as a generic term to cover all gates and risers that are returned to the melting unit for remelting; also applies to similar portions of master patterns, pattern dies, patterns, investment molds, and the finished castings.
SWARF	The stream of particles produced tangentially from an abrasive tool contact point.
TAP HOLE	Opening in the furnace breast through which the molten metal is tapped into the spout.
TAPPING	Removing molten metal from the melting furnace by opening the tap hole and allowing the metal to run into a ladle.

APPENDIX A. Glossary of Terms--Continued

TRANSFER LADLE	A ladle that may be supported on a monorail or carried on a shank and used to transfer metal from the melting furnace to the holding furnace or from furnace to pouring ladles.
TUCKING	Pressing sand with the fingers under flask bars, around gaggers, and into other places where the rammer does not give the desired density.
TUMBLING BARRELS	Rotating barrels in which castings are cleaned, also called rolling barrels and rattlers. Usually, small, star-shaped castings are loaded with the castings to aid the cleaning process.
TUYERE	An opening in the cupola shell and refractory lining through which the airblast is forced.

APPENDIX B. Health hazards potentially present in foundries--Health effects and exposure limits (by agent)

Agent	Process/Use	Major health effects	Primary target site	Standard or limit*	Reference
Acetylene	Melting and pouring emission; cutting torch	Intoxication; incoordination; unconsciousness; asphyxia	CNS	ACGIH - Asphyxiant NIOSH - 2,500 ppm ($2,662\ mg/m^3$) ceiling	[88] [264]
Acrolein	Core ovens decomposition product; pouring and shakeout where oil sand cores are used	Eye, nose, throat irritation; lacrimation; pulmonary edema	Eyes, lungs, airways	ACGIH - 0.1 ppm ($0.25\ mg/m^3$) OSHA - 0.1 ppm ($0.25\ mg/m^3$)	[88] [141]
Aluminum and aluminum oxide	Melting and pouring of aluminum alloys; deoxidant for steel alloys; mold wash refractory; ladle and furnace refractory	Respiratory effects (potential pulmonary fibrosis)	Lungs	ACGIH - $10\ mg/m^3$ (tentative)	[88] [265]
Ammonia	Coremaking decomposition product of nitrogen-containing binding materials	Respiratory irritant; gastritis; laryngeal and lung edema	Lungs, airways	ACGIH - 25 ppm ($18\ mg/m^3$) NIOSH - 50 ppm ($34.8\ mg/m^3$), 5-min ceiling OSHA - 50 ppm ($35\ mg/m^3$)	[88] [77] [141]

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*Unless specified, ACGIH TLV's, NIOSH REL's, or OSHA PEL's are 8-hour time-weighted averages (TWA's).

§No established limit or standard

APPENDIX B. Health hazards potentially present in foundries--Health effects and exposure limits (by agent)--**Continued**

Agent	Process/Use	Major health effects	Primary target site	Standard or limit*	Reference
Antimony	Metal alloy for copper and lead	Pulmonary congestion; heart, kidney, and liver effects; dermatitis; rhinitis	Kidney, liver, skin, nose, lungs	ACGIH - 0.5 mg/m^3 as Sb NIOSH - 0.5 mg/m^3, 10 hr OSHA - 0.5 mg/m^3	[88] [266] [141]
Asbestos	Furnace lining and some protective clothing; previously used in riser sleeves	Asbestosis; mesothelioma	Lungs	ACGIH - Human carcinogen Amosite - 0.5 fibers >5 μm/cc Chrysotile - 2.0 fibers >5 μm/cc Crocidolite - 0.2 fibers >5 μm/cc Other Forms - 2.0 fibers >5 μm/cc NIOSH - All Forms - 0.1 fibers >5 μm/cc OSHA - All Forms - 2.0 fibers >5 μm/cc; 10 fibers >5 μm/cc ceiling	[88] [267]
Bentonite clay	Mold binding agent	Nuisance dust	Lungs	ACGIH - 10 mg/m^3 (total dust)	[88]
Benzene	Core wash; solvent	Leukemia; CNS depression; dermatitis	CNS, skin, blood	ACGIH - 10 ppm (30 mg/m^3) (suspect human carcinogen) NIOSH - 1 ppm (3.2 mg/m^3), 60-min ceiling OSHA - 10 ppm; 25 ppm acceptable ceiling; 50 ppm maximum ceiling, 10-min	[78] [88] [141]
Beryllium	Melting and pouring; copper alloy	Berylliosis; lung cancer; dermatitis	Lungs, skin	ACGIH - 0.002 mg/m^3 (suspect human carcinogen) NIOSH - 0.5 μg/m^3, 10 hr OSHA - 2 μg/m^3; 5 μg/m^3 acceptable ceiling; 25 μg/m^3 maximum ceiling, 30-min	[143] [88] [141]

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§No established limit or standard

APPENDIX B. Health hazards potentially present in foundries--Health effects and exposure limits (by agent)--Continued

Agent	Process/Use	Major health effects	Primary target site	Standard or limit*	Reference
Cadmium	Alloying element; protective coating	Metal fume fever; cadmium poisoning; emphysema; pulmonary edema; renal changes; potential carcinogen	Lungs, kidney	ACGIH - 0.05 mg/m^3 NIOSH - Reduce exposure to lowest feasible limit OSHA - Fume: 0.1 mg/m^3, 0.3 mg/m^3 ceiling; dust: 0.2 mg/m^3, 0.6 mg/m^3 ceiling	[268] [88] [141] [269]
Carbon dioxide	Silicate-CO_2 process; melting and pouring emission; ladle preheaters; core ovens; space heaters; welding	Asphyxiation; acute O_2 deficiency	All	ACGIH - 5,000 ppm (9,000 mg/m^3) NIOSH - 10,000 ppm (18,000 mg/m^3), 10 hr; 30,000 ppm (5,400 mg/m^3), 10-min ceiling OSHA - 5,000 ppm (9,000 mg/m^3)	[270] [88] [141]
Carbon monoxide	Melting and pouring emission; decomposition product of coremaking	Behavioral and neurophysiologic changes; heart effect; acute O_2 deficiency	Blood, heart, CNS	ACGIH - 50 ppm (55 mg/m^3) NIOSH - 35 ppm (40 mg/m^3), 200 ppm (229 mg/m^3) ceiling OSHA - 50 ppm (55 mg/m^3)	[88] [141]
Cereal	Binder material	Nuisance dust	Lungs	§	[13]
Chlorine	Degassing agent for nonferrous agent	Irritation of eyes, nose, and throat; pulmonary edema and congestion; anoxia	Mucous membranes, lungs	ACGIH - 1 ppm (3 mg/m^3) NIOSH - 0.5 ppm (1.45 mg/m^3), 15-min ceiling OSHA - 1 ppm (3 mg/m^3) ceiling	[81] [88] [141]

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§No established limit or standard

APPENDIX B. Health hazards potentially present in foundries--Health effects and exposure limits (by agent)--Continued

Agent	Process/Use	Major health effects	Primary target site	Standard or limit*	Reference
Chromium	Melting, pouring, and grinding of low alloy and stainless steel and chrome alloys; chromite sand constituent	Nephritis; lung cancer; skin ulcers; dermatitis; allergic reactions; lung irritation	Kidney, lungs, skin	ACGIH - Chromium: 0.5 mg/m^3; chromium VI, water soluble: 0.05 mg/m^3; carcinogenic, chromium VI, certain water insoluble: 0.05 mg/m^3 NIOSH - Carcinogenic Cr (VI): 1 $\mu g/m^3$; other Cr (VI): 25 $\mu g/m^3$, 10 hr, 50 $\mu g/m^3$ 15-min ceiling OSHA - Chromic acid and chromates: 0.1 mg/m^3 acceptable ceiling; soluble chromic, chromous salts as Cr: 0.2 mg/m^3; metal and insoluble salts: 1 mg/m^3	[67] [88] [141]
Copper	Melting, pouring, and grinding of copper and alloys	Acute respiratory irritation; metal fume fever	Lungs	ACGIH - Fume: 0.2 mg/m^3; dust and mist: 1 mg/m^3 OSHA - Fume: 0.1 mg/m^3; dust and mist: 1 mg/m^3	[88] [141]
Cresol	Pouring decomposition product of green sand molds	Dermatitis; kidney; hepatic damage; CNS depression; nausea; cough	Skin, kidney, liver, CNS, lungs	ACGIH - 5 ppm (22 mg/m^3) NIOSH - 2.3 ppm (10 mg/m^3) OSHA - 5ppm (22 mg/m^3)	[271] [88] [141]

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§No established limit or standard

APPENDIX B. Health hazards potentially present in foundries--Health effects and exposure limits (by agent)--Continued

Agent	Process/Use	Major health effects	Primary target site	Standard or limit*	Reference
Diphenylmethane diisocyanate (MDI)	Binder component for urethane binders; decomposition product	Irritation; occupational asthma	Respiratory tract, eyes	ACGIH - 0.02 ppm (0.2 mg/m^3) ceiling NIOSH - 50 μg/m^3; 200 μg/m^3, 10-min ceiling OSHA - 0.02 ppm (0.2 mg/m^3) ceiling	[82]
Dimethylethylamine (DMEA)	Catalyst for cold box binder systems	Skin irritation; corneal edema; contact dermatitis	Eyes, lungs, skin	§	[272]
Dimethylphenol	Decomposition emission from melting and pouring	Necrosis; nausea; neurologic impairment; renal and hepatic damage	Gastrointestinal tract, CNS, liver, kidney	§	[273]
Ethane	Melting, pouring, and shakeout decomposition product	Asphyxia	Lungs	ACGIH - Asphyxiant	[274] [88]
Ethene	Melting, pouring, and shakeout decomposition product	Asphyxia	Lungs	§	
Ethyl alcohol	Constituent in hot coating in shell molding	Liver and heart muscle lesions; gastritis	Liver, heart	ACGIH - 1,000 ppm (1,900 mg/m^3) OSHA - 1,000 ppm (1,900 mg/m^3)	[88] [141]

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§No established limit or standard

APPENDIX B. Health hazards potentially present in foundries--Health effects and exposure limits (by agent)--Continued

Agent	Process/Use	Major health effects	Primary target site	Standard or limit*	Reference
Ethyl silicate	Binder	Eye and respiratory tract irritation; kidney, liver, and lung changes possible	Eyes, kidney, liver, lungs, skin	ACGIH - 10 ppm (85 mg/m^3) OSHA - 100 ppm (850 mg/m^3)	[274] [141]
Formaldehyde	Emission in molding, pouring, and shakeout areas from decomposition of binder materials	Headache; allergic reaction; pulmonary edema; eye and skin irritation; potential carcinogen	Lungs, eyes, skin	ACGIH - 1 ppm (1.5 mg/m^3) (industrial substances suspect of carcinogenic potential for man) NIOSH - Reduce to lowest feasible level OSHA - 3 ppm; 5 ppm acceptable ceiling; 10 ppm maximum ceiling, 30-min	[84] [85] [88] [141]
Furfuryl alcohol	Component of furan resin binders	Lacrimation; irritation; allergies	Eyes, skin	ACGIH - 10 ppm (40 mg/m^3) NIOSH - 50 ppm (200 mg/m^3), 10 hr OSHA - 50 ppm (200 mg/m^3)	[86] [88] [141]
Graphite	Mold release agent; foundry aggregate in nonferrous applications; green sand additive; furnace electrode; combustion soot in furnaces; ladle heating and core ovens; decomposition product of organic binders	Graphite pneumoconiosis	Lungs	ACGIH - Nuisance particulate: 5 mg/m^3 (respirable dust); 10 mg/m^3 (total dust <1% quartz)	[69] [275] [88]

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§No established limit or standard

APPENDIX B. Health hazards potentially present in foundries--Health effects and exposure limits (by agent)--Continued

Agent	Process/Use	Major health effects	Primary target site	Standard or limit*	Reference
Hexachloroethane	Degassing and grain refining agent for aluminum	CNS depression; potential carcinogen; irritation	CNS	ACGIH - 10 ppm (100 mg/m^3) NIOSH - Reduce exposure to lowest feasible level OSHA - 1 ppm (10 mg/m^3)	[88] [141]
Hexamethylene-tetramine	Catalyst in shell molding	Skin rash; urinary tract irritation; GI disturbance; nephritis with high exposure	Skin, kidney	§	[58] [274]
Hot environments	Melting and pouring; shakeout; core ovens; heat treating; welding; cranes	Heat illnesses; increased cardiovascular and respiratory strain; heat stroke	Heart, lungs, circulatory system, liver, and kidney	ACGIH - variable NIOSH - variable	[97] [165]
Hydrogen chloride	Mist produced in degassing and fluxing of nonferrous metals	Irritation; burns; tooth erosion; nasal and oral mucosa ulceration; respiratory irritation	Skin, teeth, mucosa, lungs	ACGIH - 5 ppm (7 mg/m^3) ceiling OSHA - 5 ppm	[58] [88] [141] [274]
Hydrogen cyanide	Decomposition product of nitrogen-containing binding agents	Dermatitis; asphyxia; death; neurologic changes	Skin, CNS, cardiovascular system, liver, kidney	ACGIH - 10 ppm (10 mg/m^3) ceiling NIOSH - 4.7 ppm (5 mg CN/m^3), 10-min ceiling OSHA - 10 ppm (11 mg/m^3) (Skin)	[88] [141] [276]

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§No established limit or standard

APPENDIX B. Health hazards potentially present in foundries--Health effects and exposure limits (by agent)--Continued

Agent	Process/Use	Major health effects	Primary target site	Standard or limit*	Reference
Hydrogen fluoride	Decomposition product of flux	Eye, nose and skin irritation; skin ulcers; bone effects; GI effects	Skin, eyes, nose, bones	ACGIH - 3 ppm (2.5 mg/m^3) NIOSH - 3 ppm (2.5 mg F/m^3), 10 hr; 6 ppm (5.0 mg F/m), 15-min ceiling OSHA - 3 ppm	[88] [141] [277]
Hydrogen sulfide	Emission at slag quenching operations; melting and pouring decomposition product; shakeout	Irritation; nervous system changes; respiratory paralysis; eye irritation	CNS, lungs	ACGIH - 10 ppm (14 mg/m^3) NIOSH - 10 ppm (15 mg/m^3), 10-min ceiling OSHA - 20 ppm acceptable ceiling; 50 ppm maximum ceiling, 10-min	[88] [91] [141]
Iron and iron oxide	Melting, pouring, and grinding of iron and steel; shakeout; sand and core wash additive	Pulmonary irritation	Lungs	ACGIH - Iron oxide fume: 5 mg/m^3 OSHA - Fume: 10 mg/m^3	[88] [141] [274]
Isophorone	Decomposition product of melting and pouring	Respiratory and mucosa irritation; dermatitis	Lungs, mucosa	ACGIH - 5 ppm (25 mg/m^3) ceiling OSHA - 25 ppm (140 mg/m^3)	[88] [141]
Isopropyl alcohol	Solvent for core and mold washes	Mucous membrane irritation	Mucosa	ACGIH - 400 ppm (980 mg/m^3) NIOSH - 400 ppm, 10 hr; 800 ppm, 15-min ceiling OSHA - 400 ppm (980 mg/m^3)	[88] [141] [278]

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§No established limit or standard

APPENDIX B. Health hazards potentially present in foundries--Health effects and exposure limits (by agent)--Continued

Agent	Process/Use	Major health effects	Primary target site	Standard or limit*	Reference
Lead	Alloying agent to copper base alloys; melting and pouring; grinding of lead, iron, and steel	Kidney, blood, GI and nervous system changes	Kidney, blood, CNS, gastro-intestinal tract	ACGIH - 0.15 mg/m^3 NIOSH - <100 μg/m^3, 10 hr; air level to be maintained so that worker blood lead remains $\leq$60 μg/100g OSHA - 50 μg/m^3	[64] [88] [141]
Magnesium and magnesium oxide	Melting and pouring of ductile (nodular) iron and magnesium; core wash refractory	Metal fume fever	Lungs	ACGIH - MgO fume: 10 mg/m^3 OSHA - MgO fume: 15 mg/m^3	[88] [141] [279]
Manganese	Alloying element in iron and steel; melting, pouring, and grinding of ferrous alloys; and sand addition	Pulmonary diseases; pneumonia; nervous system changes	Lungs, CNS	ACGIH - Dust and compounds: 5 mg/m^3 ceiling; fume: 1 mg/m^3 OSHA - 5 mg/m^3 ceiling	[88] [195] [141]
Methane	Emission from ovens, furnaces, and cupolas; pouring; shakeout	Asphyxiant	Lungs	ACGIH - Asphyxiant	[274] [88]
Methyl alcohol	Decomposition product of grinder systems or core washes that contain methyl alcohol; pouring; shakeout	Narcosis; dermatitis; blindness; metabolic acidosis; mucous membrane irritation	Skin, CNS	ACGIH - 200 ppm (260 mg/m^3) NIOSH - 200 ppm, 10 hr; 800 ppm, 15-min ceiling OSHA - 200 ppm (260 mg/m^3)	[88] [141] [280]

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§No established limit or standard

APPENDIX B. Health hazards potentially present in foundries--Health effects and exposure limits (by agent)--Continued

Agent	Process/Use	Major health effects	Primary target site	Standard or limit*	Reference
Mica	Mold release agent	Nodular fibrosis	Lungs	OSHA - 20 mppcf (<1% crystalline silica)	[58] [141]
Molybdenum	Melting and pouring of iron and steel	Pneumoconioses; gout	Lungs	ACGIH - Soluble: 5 mg/m^3; insoluble: 10 mg/m^3 OSHA - Soluble: 5 mg/m^3; insoluble: 15 mg/m^3	[88] [141]
Nickel	Fume from melting, pouring, and grinding of nickel and stainless steels	Dermatitis; lung and nasal cancer	Skin, lungs, nose	ACGIH - Metal: 1 mg/m^3; soluble: 0.1 mg/m^3 NIOSH - 15 µg Ni/m^3, 10 hr OSHA - 1 mg/m^3	[68] [88] [141]
Nitrogen	Furnace effluent	Anoxia	CNS	§	[274]
Nitrogen oxides	Melting and pouring	Methemoglobinemia; irritation; edema; dyspnea	Blood, lungs	ACGIH - NO_2: 3 ppm (6 mg/m^3) ceiling NIOSH - NO_2: 1 ppm (1.8 mg/m^3), 15-min ceiling; NO: 25 ppm (30 mg/m^3), 10 hr OSHA - NO_2: 5 ppm (9 mg/m^3) ceiling; NO: 25 ppm (30 mg/m^3)	[88] [141] [281]
Noise	Shakeout; furnaces	Hearing damage; neurologic effects	Ear, CNS	ACGIH - 85 dBA, 115 dBA ceiling NIOSH - 85 dBA, 10 hr; 115 dBA ceiling OSHA - 90 dBA	[88] [92] [141]

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§No established limit or standard

APPENDIX B. Health hazards potentially present in foundries--Health effects and exposure limits (by agent)--Continued

Agent	Process/Use	Major health effects	Primary target site	Standard or limit*	Reference
Paraffin wax fume	Grinding wheel application	Cancer	Skin, lungs, stomach	ACGIH - 2 mg/m^3	[88] [141]
Phenol	Binder-constituent; decomposition product of binding system	Tinnitis; pigmentary changes in skin; skin cancer; liver, CNS, and kidney changes	Skin, liver, CNS, kidney	ACGIH - 5 ppm (19 mg/m^3) NIOSH - 5.2 ppm (20 mg/m^3), 10 hr; 15.6 ppm (60 mg/m^3),15-min ceiling OSHA - 5 ppm (19 mg/m^3) (Skin)	[88] [141] [282]
Phosphoric acid	Furan resin catalyst	Eye, skin and respiratory tract irritation; dermatitis	Eyes, skin, lungs	ACGIH - 1 mg/m^3 OSHA - 1 mg/m^3	[88] [141]
Polycyclic aromatic hydrocarbons (benzo(a)pyrene, cresol, methylbenzanthracene, naphthalene)	Pouring decomposition product of sand molds; cupola melting	Animal carcinogen and mutagen; skin eruptions; liver and kidney damage; dermatitis; cataracts; nausea; hematuria	Skin, liver, kidney, eyes	Benzo(a)pyrene: ACGIH - suspect human carcinogen Cresol: ACGIH - 5 ppm (22 mg/m^3) NIOSH - 2.3 ppm (10 mg/m^3), 10 hr OSHA - 5 ppm (22 mg/m^3) (Skin) Naphthalene: ACGIH - 10 ppm (50 mg/m^3) OSHA - 10 ppm (50 mg/m^3)	[87] [88] [141] [271] [283]

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§No established limit or standard

APPENDIX B. Health hazards potentially present in foundries--Health effects and exposure limits (by agent)--Continued

Agent	Process/Use	Major health effects	Primary target site	Standard or limit*	Reference
Silica	Molding; coremaking; shakeout; furnace; ladle and furnace refractory cleaning room	Chronic lung disease; silicosis	Lungs	ACGIH - TLV mppcf: $\frac{10\ \text{mg}/^3}{\%\ \text{respirable quartz} + 2}$ (also other equations) NIOSH - Respirable free silica: 50 $\mu g/m^3$, 10 hr OSHA - Respirable quartz: (in mppcf) $\frac{250}{\%\ SiO_2 + 5}$ or $\frac{10\ mg/m^3}{\%\ SiO_2 + 2}$	[54] [88] [141] [226]
Sodium silicate	Sand binder; ladle and furnace refractory binder	Dermatitis; eye and skin burns; respiratory irritation	Skin, eyes, lungs	§	[83] [275]
Sulfur dioxide	Magnesium casting emission; core or mold binder system emission; catalyst for cold box binder system	Respiratory irritation	Lungs	ACGIH - 2 ppm (5 mg/m^3) NIOSH - 0.5 ppm (1.3 mg/m^3), 10 hr OSHA - 5 ppm (13 mg/m^3)	[90] [88] [141]

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*Unless specified, ACGIH TLV's, NIOSH REL's, or OSHA PEL's are 8-hour time-weighted averages (TWA's).

§No established limit or standard

APPENDIX B. Health hazards potentially present in foundries--Health effects and exposure limits (by agent)--Continued

Agent	Process/Use	Major health effects	Primary target site	Standard or limit*	Reference
Talc	Release agent; binder constituent	Talcosis; nodular fibrosis	Lungs	ACGIH - Respirable dust, no asbestos fibers: 2 mg/m^3; containing asbestos fibers: use asbestos TLV, not to exceed 2 mg/m^3 respirable dust OSHA - Nonasbestos-form containing <1 % quartz: 20 mppcf; fibrous: use asbestos limit	[88] [141]
Tellurium	Alloying agent for ferrous and nonferrous metals	Respiratory irritation	Lungs	ACGIH - 0.1 mg/m^3 OSHA - 0.1 mg/m^3	[88] [141]
Tin and tin oxide	Alloying element; melting and pouring emission	Stannosis; pneumoconiosis; dermal lesions	Lungs, skin	ACGIH - Metal, oxide, and inorganic: 2 mg/m^3; organic: 0.1 mg/m^3 OSHA - Inorganic except oxides: 2 mg/m^3; organic: 0.1 mg/m^3	[88] [141]
Titanium	Alloying element for aluminum; deoxidant for ferrous alloys	Mild pulmonary irritation	Lungs	ACGIH - Titanium dioxide (nuisance particulate): 5 mg/m^3 (respirable dust); 10 mg/m^3 (total dust <1% quartz) OSHA - Titanium dioxide: 15 mg/m^3	[88] [141]
Toluene	Decomposition product of mold materials	Dermatosis; CNS depression; respiratory tract and mucous membrane irritation	Skin, CNS, lungs, mucosa	ACGIH - 100 ppm (375 mg/m^3) NIOSH - 100 ppm (375 mg/m^3), 10 hr; 200 ppm (750 mg/m^3), 10-min ceiling OSHA - 200 ppm; 300 ppm acceptable ceiling; 500 ppm maximum ceiling, 10-min	[79] [88] [141]

*Unless specified, ACGIH TLV's, NIOSH REL's, or OSHA PEL's are 8-hour time-weighted averages (TWA's).
§No established limit or standard

APPENDIX B. Health hazards potentially present in foundries--Health effects and exposure limits (by agent)--Continued

Agent	Process/Use	Major health effects	Primary target site	Standard or limit*	Reference
1,1,1-Trichloroethane	Core and mold wash solvent	CNS depression; liver and kidney damage; lung and skin irritation	CNS, liver, heart, lungs, lymph nodes, skin	ACGIH - 350 ppm (1,900 mg/m^3) NIOSH - 350 ppm (1,910 mg/m^3), 15-min ceiling OSHA - 350 ppm (1,900 mg/m^3)	[88] [141] [275] [284]
1,1,2-Trichloroethane	Core and mold wash solvent	Cancer		ACGIH - 10 ppm NIOSH - Reduce exposure to lowest feasible level OSHA - 10 ppm (45 mg/m^3) (Skin)	[88] [141]
Triethylamine	Catalyst in cold box binder system	Irritation; edema; chemical sensitization	Eyes, lungs	ACGIH - 10 ppm (40 mg/m^3) OSHA - 25 ppm (100 mg/m^3)	[88] [141]
Ultraviolet radiation	Melting and pouring areas	Skin and ocular effects; skin cancer	Skin, eyes	ACGIH - variable (200-315 nm); <1 J/cm^2 for periods <1,000 sec (320-400 nm); <1 mW/cm^2 for periods >1,000 sec (320-400 nm) NIOSH - variable (200-315 nm); <1 J/cm^2 for periods <1,000 sec (315-400 nm); <1 mW/cm^2 for periods >1,000 sec (315-400 nm)	[88] [98] [141]
Vanadium	Alloying element for ferrous alloys	Conjunctiva irritation; nasal mucosa irritation; dyspnea; bronchitis; fatigue	Eyes, skin, lungs	ACGIH - V_2O_5 respirable dust and fume: 0.05 mg/m^3 NIOSH - Vanadium carbide, metallic and alloyed forms: 1 mg/m^3, 10 hr; all other vanadium compounds: 0.05 mg/m^3, 15-min ceiling	[88] [141] [285]

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*Unless specified, ACGIH TLV's, NIOSH REL's, or OSHA PEL's are 8-hour time-weighted averages (TWA's).

§No established limit or standard

APPENDIX B. Health hazards potentially present in foundries--Health effects and exposure limits (by agent)--Continued

Agent	Process/Use	Major health effects	Primary target site	Standard or limit*	Reference
Vanadium--Continued				OSHA - V_2O_5 dust: 0.5 mg/m^3 ceiling; V_2O_5 fume: 0.1 mg/m^3 ceiling; ferrovanadium: 1 mg/m^3	
Vibration	Cleaning and fettling	Vibration white finger	Fingers	NIOSH - Jobs should be redesigned to minimize use of vibrating handtools	[173]
Xylene	Core wash and core binder solvent; mold decomposition product	Irritation; narcosis; pulmonary edema	Skin, mucous membranes, lungs, CNS	ACGIH - 100 ppm (435 mg/m^3) NIOSH - 100 ppm (434 mg/m^3), 10 hr; 200 ppm (868 mg/m^3), 10-min ceiling OSHA - 100 ppm (435 mg/m^3)	[80] [88] [141]
Zinc oxide	Melting, pouring, and grinding of zinc, galvanized metal, and brass	Metal fume fever; dermatitis	Lungs, skin	ACGIH - Fume: 5 mg/m^3; total dust 1% quartz: 10 mg/m^3; respirable dust: 5 mg/m^3 NIOSH - 5 mg/m^3, 10 hr; 15 mg/m^3, 15-min ceiling OSHA - Fume: 5 mg/m^3	[66] [88] [141]
Zirconium and Zirconium oxide	Deoxidizer for ferrous alloys; ladle refractory; foundry aggregate; mold and core wash refractory	Allergic granulomas	Skin	ACGIH - 5 mg/m^3 OSHA - 5 mg/m^3	[88] [141]

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*Unless specified, ACGIH TLV's, NIOSH REL's, or OSHA PEL's are 8-hour time-weighted averages (TWA's).
§No established limit or standard

APPENDIX C. Foundry processes and potential health-related hazards (by process)

Molding and coremaking	Melting	Pouring	Shakeout and cleaning
Acrolein	Acetylene	Acetylene	Acrolein
Aluminum oxide	Aluminum (fume)	Acrolein	Aluminum (dust)
Ammonia	Antimony (fume)	Aluminum (fume)	Antimony (dust)
Bentonite clay	Asbestos	Beryllium	Beryllium (dust)
Carbon dioxide	Cadmium (fume)	Carbon dioxide	Chromium (dust)
Carbon monoxide	Beryllium (fume)	Cadmium (dust)	Carbon monoxide
Cereal	Carbon dioxide	Carbon monoxide	Copper (dust)
Diphenylmethane (MDI) diisocyanate	Chlorine	Copper (fume)	Iron (dust)
Dimethylethylamine	Chromium (fume)	Cresol	Iron oxide (dust)
Ethyl alcohol	Carbon monoxide	Chromium (fume)	Formaldehyde
Ethyl silicate	Copper (fume)	Dimethylphenol	Lead (dust)
Formaldehyde	Dimethylphenol	Diphenylmethane diisocyanate	Magnesium (dust)
Furfuryl alcohol	Hexachloroethane	Ethane	Magnesium oxide (dust)
Graphite	Hot environment	Ethene	Manganese (dust)
Hexamethylenetetramine	Hydrogen chloride	Formaldehyde	Metal dusts and oxides
Hot environment	Hydrogen fluoride	Hot environment	Molybdenum (dust)
Hydrogen chloride	Hydrogen sulfide	Hydrogen sulfide	Nickel (dust)
Hydrogen cyanide	Iron (fume)	Iron (fume)	Noise
Isopropyl alcohol	Iron oxide	Iron oxide	Polycyclic aromatic hydrocarbon
Methyl alcohol	Lead (fume)	Isophorone	Silica
Mica	Magnesium (fume)	Lead (fume)	Sulfur oxides
Noise	Magnesium oxide	Magnesium (fume)	Tellurium (dust)
Phenol	Manganese (fume)	Magnesium oxide	Thermal decomposition products of binder
Phosphine	Methane	Manganese (fume)	Tin (dust)
Silica	Molybdenum (fume)	Molybdenum (fume)	Vanadium (dust)
Sodium silicate	Nickel (fume)	Nickel (fume)	Vibration
Sulfur dioxide	Nitrogen	Nitrogen oxides	Zinc (dust)
Talc	Nitrogen oxides	Optical radiation	Zirconium
Trichloroethane	Noise	Polycyclic aromatic hydrocarbons (benzo(a)pyrene, methylbenzanthracene,naphthalene)	
Triethylamine	Optical radiation	Sulfur oxides	
Vibration	Tellurium (fume)	Tellurium (fume)	
Xylene	Tin (fume)	Tin (fume)	
	Tin oxide	Tin oxide	
	Titanium (dust)	Titanium (fume)	
	Titanium (fume)	Toluene	
	Ultraviolet radiation	Ultraviolet radiation	
	Vanadium (fume)	Vanadium (fume)	
	Zinc oxide (fume)	Zinc oxide (fume)	
	Zirconium (fume)	Zirconium (fume)	

Adapted from references in Appendix B

APPENDIX D. NIOSH sampling and analytical methods for foundry hazards

Hazard/Chemical	Methods		
	Sampling	Analytical	Number
Acetylene	Grab sample or combustible gas meter	Gas chromatography for grab sample	--
Acrolein	Solid sorbent tube. 2-(Hydroxymethyl) piperidine on XAD-2, 120 mg/60 mg. Flowrate 0.01 to 0.1 L/min. Sample size 1.5 to 48 L	Gas chromatography, nitrogen-specific detector	2501
Ammonia	Adsorption on sulfuric acid-treated silica gel. Desorption with 0.1 N sulfuric acid	Specific ion meter with ammonia gas sensing probe	S347(5)
Asbestos	Filter. 0.8-1.2 μm cellulose ester membrane, 25 mm diameter. Flowrate $\geq$0.5 L/min. Sample size 40 L (at 0.1 fiber/mL) to 1920 L (at 0.1 fiber/mL)	Microscopy, phase contrast	7400
Benzene	Solid sorbent tube. Coconut shell charcoal 100 mg/50 mg. Flowrate $\leq$0.20 L/min. Sample size 2 (10 min sample) to 30 L	Gas chromatography, flame ionization detector	1500
Cadmium (dust)	Filter. 0.8 μm cellulose ester membrane. Flowrate 1 to 3 L/min. Sample size 25 L (at 0.1 mg/m^3) to 1,500 L	Atomic absorption, flame	7048
(fume)	Filter. 0.8 μm cellulose ester membrane. Flowrate 1 L/min. Sample size 10 to 400 L	X-ray fluorescence	7200
Carbon dioxide	5-liter five-layer gas sampling bag. Flowrate 0.05 liter/min (not less than 0.01 liters/min). Sample size 3 to 4 liters	Gas chromatography	S249

Adapted from sampling and analytical methods as indicated by NIOSH criteria documents and Manual of Analytical Methods [286,287,288,289,290,291,292,293]

APPENDIX D. NIOSH sampling and analytical methods for foundry hazards--Continued

Hazard/Chemical	Methods		
	Sampling	Analytical	Number
Carbon monoxide	5-liter five-layer gas sampling bag. Flowrate 0.05 liter/min (not less than 0.01 liters/min). Sample size 3 to 4 liters	Electrochemical analysis	S340(4)
Carbon tetrachloride	Solid sorbent tube. Coconut shell charcoal, 100 mg/50 mg. Flowrate 0.01 to 0.2 L/min. Sample size varies	Gas chromatography, flame ionization detector	1003
Chlorine	Midget fritted bubblers with 10 ml sampling solution, 1-2 liters/min for 15 min + 6 ml 0.005% methyl orange to 100 ml H20 + 0.15-0.20 ml of 5.0 N HCL + 1 drop butanol (optional)	Colorimetry using spectrophotometery	209
Chromium VI	Filter. 0.8 µm cellulose ester membrane. Flowrate 1 to 4 L/min. Sample size 8 L (at 0.025 mg/m^3) to 400 L	Atomic absorption, flame	7024
Coal tar	0.8 µm silver membrane filter preceded by Gelman type A or equivalent glass filter (3 piece)	Weighing after extraction	217
Cresol	Solid sorbent tube. Silica gel, 150 mg/75 mg. Flowrate 0.01 to 0.2 L/min. Sample size 5 L (at 5 ppm) to 20 L	Gas chromatography, flame ionization detector	2001
Crystalline silica	1. Cyclone plus filter. 10 mm nylon cyclone plus 5 µm PVC membrane. Flowrate 1.7 L/min. Sample size 800 L (at 0.05 mg/m^3) to 1,000 L	1. X-ray powder diffraction	7500

Adapted from sampling and analytical methods as indicated by NIOSH criteria documents and Manual of Analytical Methods [286,287,288,289,290,291,292,293]

APPENDIX D. NIOSH sampling and analytical methods for foundry hazards--Continued

Hazard/Chemical	Methods		
	Sampling	Analytical	Number
	2. Cyclone plus filter. 10 mm nylon cyclone plus 0.8 µm or 5 µm PVC or MCE membrane. Flowrate 1.7 L/min. Sample size 400 to 800 L	2. Visible absorption spectrophotometry	7601
	3. Cyclone plus filter. 10 mm nylon cyclone plus 0.8 µm or 5 µm PVC or MCE membrane. Flowrate 1.7 L/min. Sample size 400 to 800 L	3. Infrared absorption spectrophotometry	7602
Diphenylmethane diisocyanate (MDI)	Impinger. Solution of 1-(2-methoxyphenyl)-piperazine in toluene. Flowrate 1 L/min. Sample size 350 to 600 L	High performance liquid chromatography, ultraviolet detection	5505
Ethanol	Solid sorbent tube. Coconut shell charcoal, 100 mg/50 mg. Flowrate 0.05 L/min. Sample size 0.1 to 1 L	Gas chromatography, flame ionization detection	1400
Formaldehyde	Filter plus impingers. 1 µm PTFE membrane and 2 impingers, each with 20 ml. 1% sodium bisulfite solution. Flowrate 0.2 to 1 L/min. Sample size 2 L at 1 min) to 100 L	Visible absorption spectrophotometry	3500
Furfuryl alcohol	Adsorption on Porapak Q. Desorption with acetone	Gas chromatography	S365(4)
Hot environments	WBGT or WGT	--	--
Hydrogen cyanate/ cyanate salts	Filter plus bubbler. 0.8 µm cellulose ester membrane plus 10 ml. 0.1 N KOH. Flowrate 0.5 to 1 L/min. Sample size: (min) 10 L at 5 mg/m^3 (as CN^-); (max) 180 L at 11 mg/m^3 (as CN^-)	Ion-specific electrode	7904

Adapted from sampling and analytical methods as indicated by NIOSH criteria documents and Manual of Analytical Methods [286,287,288,289,290,291,292,293]

APPENDIX D. NIOSH sampling and analytical methods for foundry hazards--Continued

Hazard/Chemical	Methods		
	Sampling	Analytical	Number
Hydrogen fluoride	Filter plus treated filter. 0.8 µm cellulose ester membrane followed by a Na_2CO_3 treated cellulose pad. Flowrate 0.2 to 0.5 L/min. Sample size 3 to 100 L	Ion-specific electrode	7902
Hydrogen sulfide	Adsorption on molecular sieve. Sample size 5 liters. Flowrate 0.15 to 0.2 liters/min.	Gas chromatography with a flame photometric detector in the sulfur mode	296(6)
Inorganic fluorides	Solid sorbent tube. Washed silica gel, 400 mg/200 mg with glass fiber filter plug	Ion-chromatography	7903
Inorganic lead	Filter 0.8 µm cellulose ester membrane. Flowrate 1 to 4 L/min. Sample size 300 to 800 L	Atomic absorption, flame	7082
Inorganic mercury	Solid sorbent tube. 30 mg silvered Chromosorb P, with glass fiber prefilter. Flowrate 0.01 to 0.2 L/min. Sample size 0.5 to 7 L	Atomic absorption, flameless	6000
Iron and iron oxide	Filter. 0.8 µm cellulose ester membrane. Flowrate 1 L/min. Sample size 10 to 400 L	X-ray fluorescence	7200
Methyl alcohol	Solid sorbent tube. Silica gel, 100 mg/50 mg. Flowrate 0.02 to 0.2 L/min. Sample size 1 L (at 200 ppm) to 5 L	Gas chromatography, flame ionization detector	2000
Nitrogen oxides	Passive. Palmes tube with three triethanolamine-treated screens. Sampling time: (min) 15 min at 5 ppm; (max) 8 hr at 10 ppm	Visible absorption spectrophotometery	6700

Adapted from sampling and analytical methods as indicated by NIOSH criteria documents and Manual of Analytical Methods [286,287,288,289,290,291,292,293]

APPENDIX D. NIOSH sampling and analytical methods for foundry hazards--Continued

Hazard/Chemical	Methods		
	Sampling	Analytical	Number
Noise	'A' weighted sound level audiometer	--	--
Phenol	Bubbler. 0.1 N sodium hydroxide. Flowrate 0.2 to 1 L/min. Sample size 26 to 240 L	Gas chromatography, flame ionization detector	3502
Polycyclic aromatic hydrocarbons	Solid sorbent tube, coconut shell charcoal, 100 mg/50 mg. Flowrate and volume vary	Gas chromatography, flame ionization detector	1501
Sulfur dioxide	0.8 μm cellulose membrane filter/ midget impinger containing 15 ml-0.3 N hydrogen peroxide solvent	Titration, colorimetry	S308(4)
Toluene	Adsorption on charcoal in tube. Flowrate 0.20 liter/min. Desorption with carbon disulfide	Gas chromatography with flame ionization detector	S343
Trichloroethane (methyl chloroform)	Solid sorbent tube, coconut shell charcoal, 100 mg/50 mg. Flowrate 0.01 to 0.2 L/min. Sample size varies	Gas chromatography, flame ionization detector	1003
Triethylamine	Midget bubbler with 10 ml. 0.05 M sulfuric acid. Basification with 4 M sodium hydroxide	Gas chromatography, flame ionization detector	S152
Ultraviolet radiation	Phototubes and meters. Narrow band filters	--	--
Vanadium	Filter. 0.8 μm, cellulose ester membrane. Sample size 5 to 2,000 L	Inductively coupled argon plasma, atomic emission spectroscopy	7300

Adapted from sampling and analytical methods as indicated by NIOSH criteria documents and Manual of Analytical Methods [286,287,288,289,290,291,292,293]

APPENDIX D. NIOSH sampling and analytical methods for foundry hazards--Continued

Hazard/Chemical	Methods		
	Sampling	Analytical	Number
Xylene	Solid sorbent tube, coconut shell charcoal, 100 mg/50 mg. Flowrate $\le$0.20 L/min. Sample size 12 to 23 L	Gas chromatography, flame ionization detector	1501
Zinc oxide	Filter. 0.8 µm PVC membrane, 25 mm diameter, in open-face cassette. Flowrate 1 to 3 L/min. Sample size 10 to 400 L	X-ray powder diffraction	7502

Adapted from sampling and analytical methods as indicated by NIOSH criteria documents and Manual of Analytical Methods [286,287,288,289,290,291,292,293]

APPENDIX E. NIOSH recommendations for medical monitoring for foundry hazards

Hazard	Medical recommendations	Reference
Acetylene	Monitoring as specified by criteria document	[264]
Ammonia	Monitoring as specified by criteria document	[77]
Antimony	Comprehensive physical exam, chest x ray, electrocardiogram, and pulmonary function studies	[266]
Asbestos	Chest x ray, pulmonary function studies, and monitoring as specified in NIOSH testimony	[294]
Benzene	Complete blood count (CBC) with indices	[78]
Cadmium	Chest x ray, pulmonary function studies, CBC, blood urea nitrogen, special blood studies, urinalysis, and monitoring as specified by current intelligence bulletin	[295]
Carbon dioxide	Monitoring as specified by criteria document	[270]
Carbon monoxide	Monitoring as specified by criteria document	[71]
Carbon tetrachloride	Ability to use appropriate respirators and liver function tests	[296]
Chlorine	Monitoring as specified by criteria document	[81]
Chromium (VI)	Chest x ray, sputum cytology, liver function tests, and urinalysis	[67]
Coal tar	Chest x ray, pulmonary function studies, sputum cytology, liver function tests, and urinalysis	[87]
Cresol	CBC, liver function tests, urinalysis, and monitoring as specified by criteria document	[271]

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APPENDIX E. NIOSH recommendations for medical monitoring for foundry hazards--Continued

Hazard	Medical recommendations	Reference
Crystalline silica	Chest x ray and pulmonary function tests	[54]
Diphenylmethane diisocyanate (MDI)	Pulmonary function studies and monitoring as specified by criteria document	[82]
Formaldehyde	Ability to use appropriate respirators and monitoring as specified by current intelligence bulletin	[85]
Furfuryl alcohol	Ability to use appropriate respirators and monitoring as specified by criteria document	[86]
Hot environment	Monitoring as specified by criteria document	[97] [165]
Hydrogen cyanide/ cyanide salts	Ability to use appropriate respirators and monitoring as specified by criteria document	[276]
Hydrogen fluoride (Inorganic fluorides)	Visual tests, chest x rays, and pulmonary function tests	[277]
Hydrogen sulfide	Ability to use appropriate respirators and monitoring as specified by criteria document	[91]
Isopropyl alcohol	Chest x ray, ability to use appropriate respirators, liver function tests, and monitoring as specified by criteria document	[278]
Lead, inorganic	CBC, special blood studies, urinalysis, and monitoring as specified by criteria document	[64]
Methyl alcohol	Monitoring as specified by criteria document	[280]

APPENDIX E. NIOSH recommendations for medical monitoring for foundry hazards--Continued

Hazard	Medical recommendations	Reference
Nickel, inorganic	Chest x ray, pulmonary function studies, sputum cytology, and monitoring as specified by criteria document	[68]
Nitrogen oxides	Pulmonary function studies and ability to use appropriate respirators	[281]
Noise	Audiograms	[92]
Phenol	Ability to use appropriate respirators, CBC, and urinalysis	[282]
Sulfur dioxide	Ability to use appropriate respirators and monitoring as specified by criteria document	[90]
Toluene	CBC and urinalysis	[79]
Trichloroethane	Monitoring as specified by criteria document	[284]
Ultraviolet radiation	Monitoring as specified by criteria document	[98]
Vanadium	Chest x ray and pulmonary function studies	[285]
Xylene	CBC, liver function tests, and urinalysis	[80]
Zinc oxide	Monitoring as specified by criteria document	[66]

APPENDIX F. OSHA regulations pertaining to the foundry industry

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Subpart D, Walking-working Surface; Sections:

- 1910.22-General requirements
- 1910.22(a)-Housekeeping
- 1910.23-Guarding floor and wall openings and holes
- 1910.24-Fixed industrial stairs
- 1910.25-Portable wood ladders
- 1910.26-Portable metal ladders
- 1910.27-Fixed ladders
- 1910.28-Safety requirements for scaffolding
- 1910.29-Manually propelled mobile ladder stands and scaffolds (towers)
- 1910.30-Other working surfaces

Subpart E, Means of Egress; Sections:

- 1910.36-General requirements
- 1910.37-Means of egress, general

Subpart F, Powered Platforms, Manlifts, and Vehicle-Mounted Work Platforms; Sections:

- 1910.66-Power platforms for exterior building maintenance
- 1910.67-Vehicle-mounted elevating and rotating work platforms
- 1910.68-Manlifts

Subpart G, Occupational Hazards and Environmental Control; Sections:

1910.94-Ventilation
- 1910.95-Occupational noise exposure
- 1910.96-Ionizing radiation

Subpart H, Hazardous Materials; Sections:

- 1910.101-Compressed gases (general requirements)
- 1910.102-Acetylene
- 1910.103-Hydrogen
- 1910.104-Oxygen

Subpart I, Personal Protective Equipment; Sections:

- 1910.132-General requirements
- 1910.133-Eye and face protection
- 1910.134-Respiratory protection
- 1910.135-Occupational head protection
- 1910.136-Occupational foot protection
- 1910.137-Electrical protective devices

Subpart J, General Environmental Controls; Sections:

- 1910.141-Sanitation
- 1910.144-Safety color code for marking physical hazards
- 1910.145-Specifications for accident prevention signs and tags

Subpart K, Medical and First Aid; Section:

- 1910.151-Medical services and first aid

Subpart L, Fire Protection; Sections:

- 1910.157-Portable fire extinguishers
- 1910.158-Standpipe and hose systems
- 1910.159-Automatic sprinkler systems
- 1910.160-Fixed extinguishing systems; general
- 1910.161-Fixed extinguishing systems, dry chemical
- 1910.163-Fixed extinguishing systems, water spray and foam

Subpart M, Compressed Gas and Compressed Air Equipment; Section:

- 1910.166-Inspection of compressed gas cylinders
- 1910.167-Safety relief devices for compressed gas cylinders
- 1910.168-Safety and relief devices for cargo and portable tanks storing compressed gases
- 1910.169-Air receivers

Adapted from 29 CFR 1910 [141]

APPENDIX F. OSHA regulations pertaining to the foundry industry--Continued

Subpart H, Hazardous Materials; Sections: Continued

- 1910.105-Nitrous oxide
- 1910.106-Flammable and combustible liquids
- 1910.107-Spray finishing using flammable and combustible materials
- 1910.108-Dip tanks containing flammable or combustible liquids
- 1910.110-Storage and handling of liquefied petroleum gases

Subpart O, Machinery and Machine Guarding; Sections:

- 1910.212-General requirements for all machines
- 1910.213-Woodworking machinery requirements
- 1910.215-Abrasive wheel machinery
- 1910.219-Mechanical power-transmission apparatus

Subpart P, Hand and Portable Powered Tools and Other Hand-held Equipment; Sections:

- 1910.242-Hand and portable powered tools and equipment, general
- 1910.243-Guarding of portable powered tools
- 1910.244-Other portable tools and equipment

Subpart N, Materials Handling and Storage; Entire Subpart.

Subpart Q, Welding, Cutting, and Brazing; Section:

- 1910.252-Welding, cutting, and brazing

Subpart S, Electrical; Entire Subpart.

Subpart Z, Toxic and Hazardous Substances; Sections:

- 1910.1000-Air Contaminants
- 1910.1001-Asbestos
- 1910.1025-Lead

Adapted from 29 CFR 1910 [141]

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